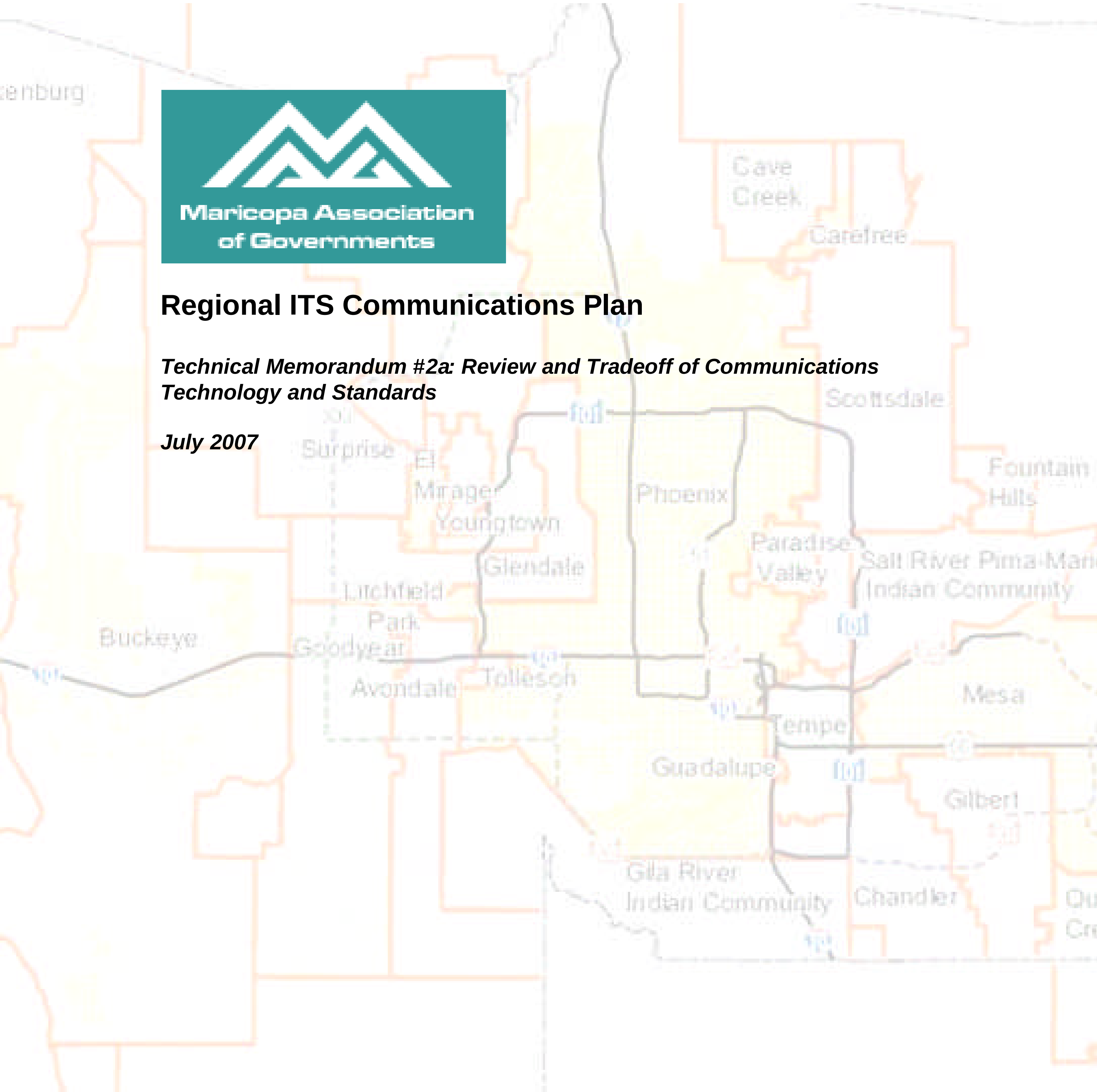
Maricopa Association of Governments

Regional ITS Communications Plan

Technical Memorandum #2a: Review and Tradeoff of Communications Technology and Standards

July 2007



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Communications Technology and Standards Tradeoff Analysis Relative to Deployment of a Regional ITS Architecture

1.0 Prior ITS Deployments in the MAG Region

Intelligent Transportation System (ITS) deployment in the MAG region (ADOT) followed mainstream ITS technology and communications architecture deployments made popular during the mid-1990s. These deployments were best supported, by deploying Synchronous Optical Network (SONET) technology as a “transport” architecture for the Metropolitan Area Network (MAN). Additionally, SONET networks were deployed since bridge/routing of both Ethernet data and encoded National Standards Television Committee (NTSC) video could be transported across a common, open-standards network architecture. SONET is an open standard defined by Telcordia’s GR-253-CORE and GR-1230-CORE specifications, and supports a number of options for protection switching architectures. SONET based networks offer 99.999% availability, and recovery from single fiber failures in less than 50 milliseconds. Because SONET based systems offer guaranteed (synchronous) delivery for all encapsulated data, it was considered the “benchmark” transport technology for supporting digital video and voice communications for both Metropolitan and Wide Area Networks (WANs).

Current planning for the Phoenix area is to continue the deployment of SONET equipment to form fiber rings, which will support regional center-to-center and field aggregation communications requirements. Where communications bandwidth is considered limited, the plan calls for deployment and use of a Coarse Wave Division Multiplexing (CWDM) overlay network as a method to increase network capacity. The proposed deployment of CWDM equipment would lead to an additional equipment layer in the overall network architecture.

The CWDM overlay network would allow multiple user groups to place information on the regional network, effectively separated by using different wavelengths of light. Since CWDM is largely protocol agnostic, both jurisdictional and agency feeds onto the network could be either Ethernet or SONET. However, to provide communications interoperability would require the use of bridge-router technology. Without this technology in place, SONET will not talk directly to Ethernet.

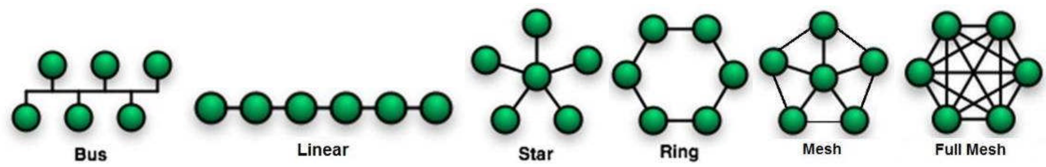
The scope of this report is to provide a discussion of current communications technology, and trade-off important characteristics relevant towards the deployment of such equipment with regard to support for regional ITS, center-to-center communications. The report will conclude with a recommendation for the most suitable technology for the application environment and one that is based on fiber optic technology.

2.0 ITS Communications Topology Prerequisites

ITS communications are designed such that ITS field device connections can be connected using a broadband communications backbone architecture. The primary purpose of the ITS communications backbone is to provide the “channel” over which digital information is sent from the field to TMC, and from the TMC to other ITS related centers, such as an EMC or EOC.

Modern communications architectures (topologies) are supported by transmission of data across various communications media, such as fiber optic cable, copper cable and free air space. These topologies host different configurations, primarily based on the level of communications redundancy desired. Typically, a redundant communications channel will have an associated protection-switching scheme applied that provides a backup channel should the primary fail or become unavailable. In addition, topologies are also defined by the intended purpose of communications network. For example, some network topologies are used to collect information from remote locations and concentrate that information into a single larger, aggregate channel for distribution across large distances. Historically the term “Add-Drop Multiplexing” (ADM) and more recently “Metro-Edge” switching as related to IP-centric networking describe the communications aggregation process. Figure 2.0-1 provides basic examples of communications network architectures. Historically, ITS communications have been built using combinations of bus, point-to-point (linear), point-to-multipoint (star), ring and mesh architectures.

Figure 2.0-1 Basic Examples of Communications Network Architectures



Performance associated with communications architectures is typically defined by a few parameters. The term “bandwidth”, as related to a network segment or overall architecture, defines the overall communications capacity of the network and is commonly measured in millions of bits per second (Mbps). Communications “availability” refers to the reliability of the network equipment as indicated by 99.999% per year for telecommunications equipment. Other important features associated with communications architectures include the ability of the network to recover from a failure within a specific amount of time. For example, carrier grade networks recover from an equipment failure within 50 milliseconds in order to preserve the continuity of digital voice and video communications. Overall communications availability is a function of equipment/network Mean-Time-Between-Failure (MTBF) and Mean-Time-To-Recovery (MTTR) characteristics, which are related to equipment design and network architecture supported. ITS backbone communications are best built on redundant topologies. Table 2.0-1 provides a description of network availability in terms of downtime.

Table 2.0-1 Typical Availability of Network Architectures and Related Equipment

Availability %	Downtime per year	Downtime per month*	Downtime per week
90%	36.5 days	72 hours	16.8 hours
95%	18.25 days	36 hours	8.4 hours
98%	7.30 days	14.4 hours	3.36 hours
99%	3.65 days	7.20 hours	1.68 hours
99.5%	1.83 days	3.60 hours	50.4 min
99.8%	17.52 hours	86.23 min	20.16 min
99.9%	8.76 hours	43.2 min	10.1 min
99.95%	4.38 hours	21.56 min	5.04 min
99.99%	52.6 min	4.32 min	1.01 min
99.999%	5.26 min	25.9 s	6.05 s
99.9999%	31.5 s	2.59 s	0.605 s

2.1 Fiber Optic Technologies

Architectures based on fiber optic technology have certain advantages when compared with other methods network deployment. Fiber optic cable is manufactured from a dielectric (insulator) material. Communications equipment operating over fiber is not susceptible Electro-Magnetic Interference (EMI) or Radio Frequency Interference (RFI) between communications terminals. Optical based equipment is furthermore isolated from failures due to a lightning strike's surge current propagation between communications interfaces. Another advantage for using fiber-based technologies is communications bandwidth. All other forms of communications fall at least an order of magnitude below the capacities achieved with fiber-based equipment.

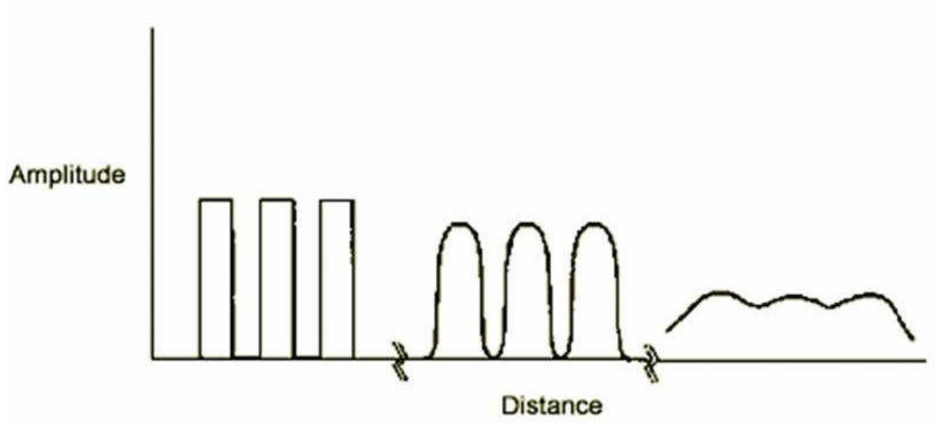
Fiber based systems provide a greater level of network availability over wireless communications. For example, SONET and Gig-E terminals routinely provide 99.999% availability in contrast to digital microwave systems providing a maximum of 99.99% availability. Fiber optic communications are the "gold" standard for fixed communication infrastructures.

Signal propagation over Single Mode Fiber Optic (SMFO) cable provides the best distance separation between equipment terminals versus bandwidth capability available. However, fiber optic cable does have bandwidth limitations and not all specifications for SMFO cable are equal. It is recommended that new fiber installations be constructed using a high quality, dispersion compensated fiber cables.

2.1.1 Dispersion Characteristics of Single Mode Fiber

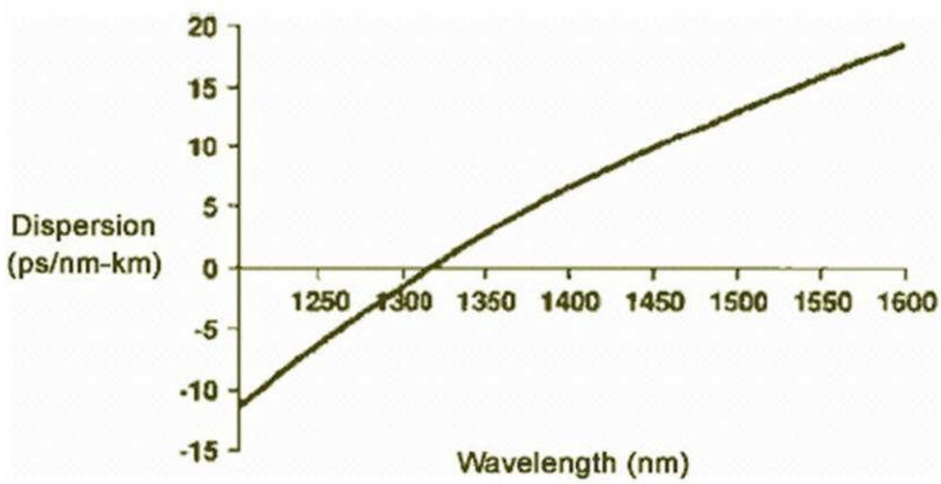
Dispersion is the time distortion of an optical signal that results from the time of flight differences of different components of that signal, typically resulting in pulse broadening (see Figure 2.1.1-1). In digital transmission, dispersion limits the maximum data rate, the maximum distance, or the information-carrying capacity of a single-mode fiber link.

Figure 2.1.1-1 Effects of dispersion on digital signals



Single-mode fiber dispersion varies with wavelength and is controlled by fiber design (see Figure 2.1.1-2). The wavelength at which dispersion equals zero is called the zero-dispersion wavelength (λ 0). Fiber has its maximum information-carrying capacity at this wavelength. For standard single-mode fibers, this is in the region of 1310 nm. The units for dispersion are also shown.

Figure 2.1.1-2 Typical Single Mode Fiber Dispersion Characteristics

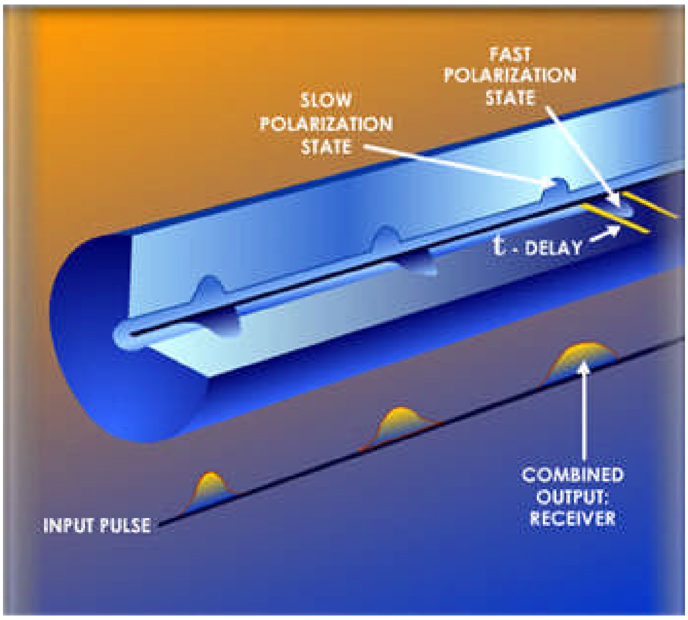


Chromatic dispersion consists of two kinds of dispersion. Material dispersion refers to the pulse spreading caused by the specific composition of the glass.

Waveguide dispersion results from the light traveling in both the core and the inner cladding glasses at the same time but at slightly different speeds. The two types can be balanced to produce a wavelength of zero dispersion anywhere within the 1310 nm to 1650 nm operating window.

PMD is a key limiter in the deployment of $\geq$ 10-Gbit/sec optical systems. To the first order, PMD is due to an asymmetry of the fiber core, in which light polarized in one-axis travels faster than light polarized in the orthogonal axis ($\pm$ 90°). This means that the leading and trailing edges for any bit transmitted over a given length of fiber will reach the receiver at two different times, ultimately resulting in bit errors. The effects from PMD can be amplified by changes in ambient temperature and by movement of the fiber. Typically, fiber optic links are designed to accommodate an acceptable margin associated with the PMD effect. Figure 2.1.1-3 illustrates the effect of Polarization Mode Dispersion in single mode fiber.

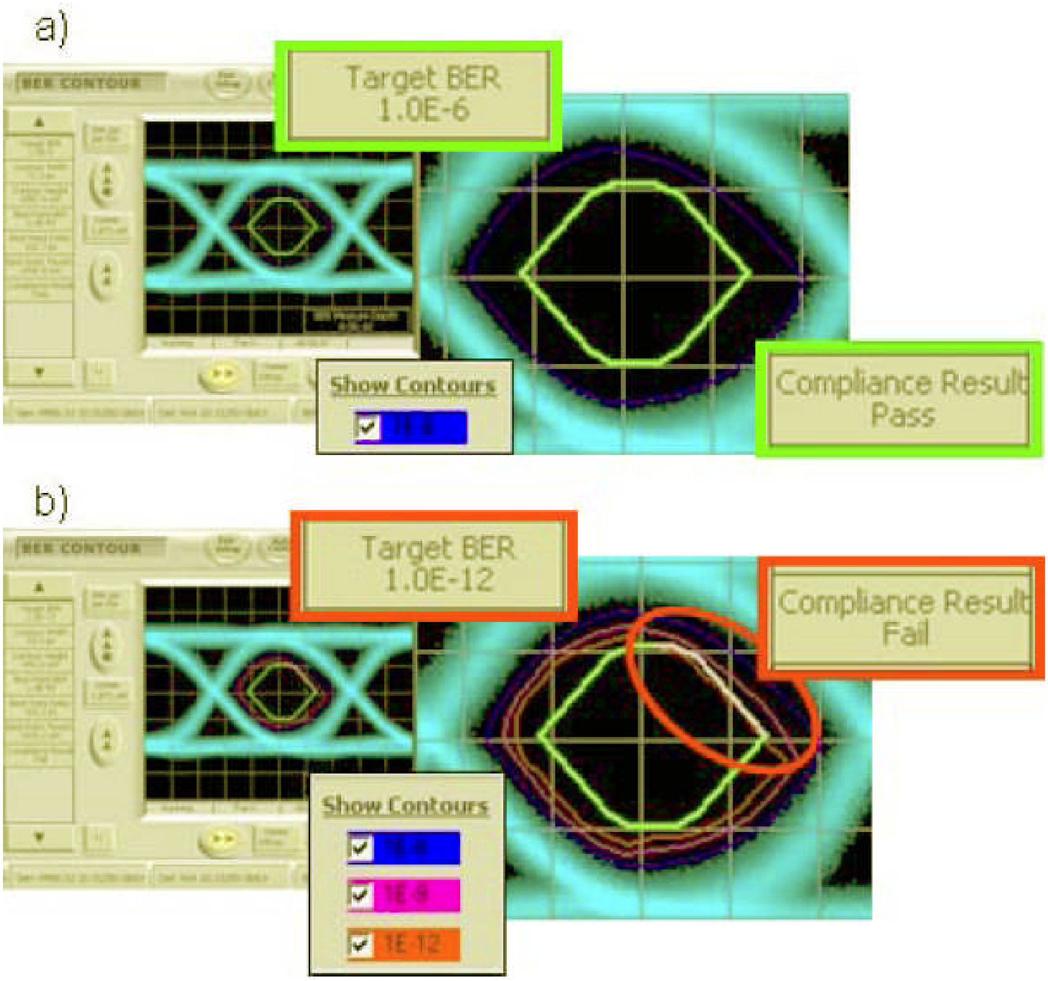
Figure 2.1.1-3 Effect of Polarization Mode Dispersion (PMD)



PMD effects on optical communications have been addressed by fiber cable manufacturers. Several brands of modern fiber address the issues surrounding PMD based on the type of fiber deployment required to support the network architecture (Corning SM-28e, MetroCor & LEAF fiber). Consideration for PMD effects requires consideration in future system designs, especially for those incorporating Wave Division Multiplexing (WDM) technology. Outside from deployment of state of the art fiber, other methods for PMD correction may be applied. One such method is to deploy optical signal regenerators to correct the original signal masking.

Essentially, if the PMD effect is substantial on a network link the receiver cannot distinguish between a digital 0 or 1 bit. This phenomenon is commonly known as digital bit errors. The effects of PMD for an optical signal can be measured as the rise and fall time of the digital signal with respect to a pre-defined bit mask (eye diagram). The bit mask defines the minimum characteristics for pulse rise time, width, amplitude, fall time and jitter. Figure 2.1.1-4 shows the 10 GigE mask (the feature is called Compliance Contour). Additionally, the effects of PMD will vary with respect to each operational wavelength transmitted across the fiber.

Figure 2.1.1-4 shows the 10 GigE mask (the feature is called Compliance Contour). The 10 GigE mask passes comfortably at 10–6 BER (Figure 2.1.1-4(a)), but not at 10–12, as seen in Figure 2.1.1-4 (b).



All of the aforementioned dispersion effects related to chromatic (CD) and polarization modes (PMD) contribute to the overall differential group delay expressed for a particular fiber.

3.0 Regional MAG ITS Backbone Technology Review and Trade-Off Analysis

This report provides a high-level discussion of current, state-of-the-art communications technologies, their associated network topologies and capability to support multimedia. Each technology candidate has been evaluated to determine its suitability for deployment as a platform to support a regional Intelligent Transportation System (ITS) network.

Results from Technical Memorandum #1 of this project have been used to provide an understanding of network bandwidth, IP video multicast and data loading.

This report will classify available technology based on the following criteria:

- communications media used,
- support from open standards committees,
- technology maturity with respect to obsolescence,
- communications bandwidth,
- ability to support multimedia,
- Quality of Service (QoS),
- communications reliability
- communications availability
- environmental suitability for ITS,
- associated technology deployment costs,
- associated technology maintenance costs,
- forwards compatibility with emerging technology
- backwards compatibility with existing technology

This report shall maintain emphasis on communications standards and technologies that are not only well suited, but capable of supporting the backbone and edge requirements of an integrated regional network.

3.1 Fiber Optic-Based Communications Technologies

Technologies based on fiber optics provide the greatest bandwidth, reliability, security and signal fidelity (noise immunity) over any other form of communications. Fiber optics are also immune to propagation of surge current due to lightning strike or irregular power conditions. There are two basic types of fiber, single mode and multi mode, and they never interconnect without the use of supporting electronics. Single mode fiber is used for Outside Plant (OSP) applications such as interconnecting communications equipment in a MAN or WAN environment. Another important factor to consider is the network bandwidth across the fiber. Should any communications require ten (10) Gbps or greater, a need exists to specify dispersion compensated fiber, which negates the effect of Pulse Mode Dispersion (PMD) across the fiber.

3.1.1 Gigabit Ethernet

Gigabit Ethernet technology, fully backward compatible with the existing Ethernet protocol, increases speed tenfold over Fast Ethernet to 1 gigabit per second (Gbps). The Gigabit Ethernet protocol, ratified by IEEE under the 802.3-2000 standard, encompasses the previous 802.3z and 802.3ab standards. The original Ethernet specification was defined by the frame format and support for CSMA/CD protocol, full duplex operation, flow control, and management objects as defined by the IEEE 802.3 standard. Gigabit Ethernet looks identical to Ethernet from the data link layer upward and implements all these functions. The most important changes from Fast Ethernet to Gigabit Ethernet include the data rates and the additional support of full duplex operation. Gigabit Ethernet supports both Unshielded Twisted Pair (UTP) and fiber optic media to be able to deliver 1 Gbps data rates.

Gigabit Ethernet technology supports ring, mesh, bus and point-to-point network architectures. Modern Gig-E devices support interface redundancy, as well as Layer 2 and Layer 3 protection switching mechanisms. Ethernet Automatic Protection Switching (RFC 3619) provides layer 2 protection switching on Gig-E optical interfaces within 50 msec. Additionally, Layer 3 protocols such as Rapid Spanning Tree Protocol (RSTP) provide re-routing of packet data as related to routing table information ($\geq$250 msec).

Quality of Service (QoS) is provided by both ISO Layer 2 and Layer 3 protocols, but Layer 3 is most important in achieving distribution of multimedia content across MAN & WAN environments. Layer 2 Type of Service (ToS) is determined by IEEE 802.1Q & 802.1P Virtual Local Area Network (VLAN) tagging. Layer 3 QoS is integral to Internet Protocol (IP) packet header information contained in the Differentiated Service Code Point (DSCP) byte. The DSCP value is processed by the Gig-E switch in determining priority status of packets such as video or voice communications.

IP multicast is supported on Gig-E backbone switches, using the Protocol Independent Multicast (PIM) protocol. Two versions of PIM are currently in use. The first, PIM Dense Mode, floods the network with video and selectively prunes the video stream from any switch that does not have a client request. This leaves a single stream of video on the network backbone after the process is complete. The second method, PIM sparse mode, uses pre-established Ethernet backbone switches to serve as “rendezvous points” from which the video is distributed. This method does not flood the network with video upon a client request, and leaves a copy of the video at the rendezvous point for distribution to subnets. Additionally, Ethernet supports the use of Jumbo Frames, which minimizes the amount of processor overhead required for the transmission of large file types such as streaming video.

Current Ethernet switch configurations provided by multiple vendors allow for the upgrade of fast Ethernet optical ports to Gig-E using Gigabit Integrated Circuit

(GBIC) technology. The caveat is that the switch fabric (backplane) must support the higher information loading created. The same philosophy is held for Gig-E upgrades to 10Gig-E.

Interoperability with, and interconnection to Gig-E technology is well understood. Most jurisdictions currently utilize Ethernet technology in the deployment of departmental computer networks, and are typically maintained by internal Information Technology staff. Larger municipalities have deployed both Gig-E and 10Gig-E technology to support interconnection of departments in a MAN environment. Without question, 10/100/1000 Mbps Ethernet is the world's most ubiquitous networking technology. Over 90 percent of today's network-attached desktops are attached with Ethernet. Since 1985, over 300 million 10, 100, and 1000 Mbps Ethernet ports have shipped with a market value exceeding billions of U.S. dollars. Once volume shipments begin to ramp, 10 Gigabit Ethernet interfaces are expected to be a very cost-effective means of deploying 10-Gbps bandwidth. The ubiquity of Ethernet makes it easy to find human and other resources to manage Ethernet networks. Because 10 Gigabit Ethernet is still Ethernet, it minimizes the IT manager's learning curve by maintaining the same management tools and architecture.

Gig-E equipment features include:

- Support for Ethernet Automatic Protection Switching ($\leq$ 50 msec.)
- Cost less to replace SONET with Gig-E than to upgrade
- Baseline configuration for 2 x 1 Gbps and 8 x 10/100 Mbps = $8,000
- Open standards compliant
- Comparable bandwidth to existing RCN
- Offers highly reliable communications
- Supports multimedia content
- Offers layer 2 and layer 3 Quality of Service (Diff-Serv)
- forwards compatibility with emerging technology
- backwards compatibility with existing technology

3.1.2 10 Gigabit Ethernet (10GigE)

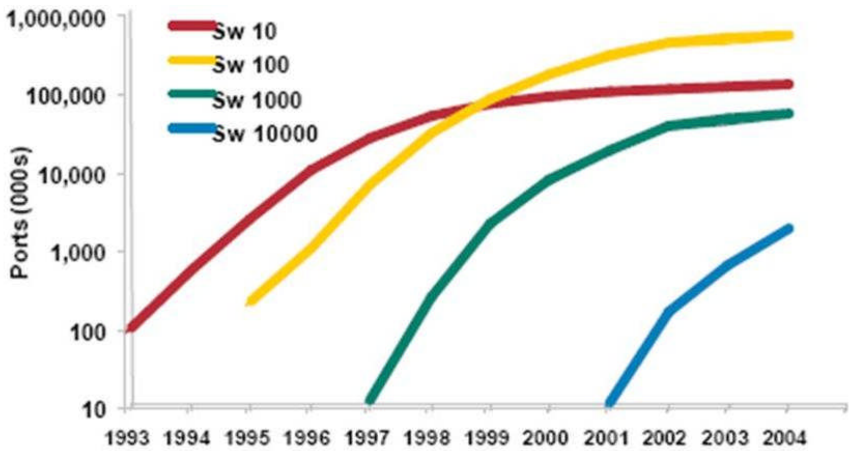
10 Gigabit Ethernet was formally ratified as an IEEE 802.3 Ethernet standard in June 2002. This technology is the next step for scaling the performance and functionality of enterprise and service provider networks because it combines multi-gigabit bandwidth and intelligent services in order to achieve scaled, intelligent, multi-gigabit networks with network links that range in speed from 10 Mbps to 10,000 Mbps. Since March 1999, the Ethernet industry has been working on increasing the speed of Ethernet from one to ten gigabits per second. This technology is very significant because not only will Ethernet run at 10 Gigabits per second and serve as a local-area network (LAN) connection, but it will also work in metropolitan-area networks (MANs) and wide-area networks (WANs). With 10 Gigabit Ethernet, network managers will be able to build LANs, MANs, and WANs using Ethernet as the end-to-end Layer 2 transport.

With this new Ethernet technology, bandwidth can be scaled from one to ten gigabits per second without sacrificing any of the intelligent network services such as Layer 3 switching, quality of service (QoS), caching, server load balancing, security, and policy-based networking. These services can be delivered at 10 Gbps line rates over the Ethernet network and supported over all network physical infrastructures in the LAN, MAN, and WAN.

10 Gigabit Ethernet is Ethernet. 10 Gigabit Ethernet uses the IEEE 802.3 Ethernet media access control (MAC) protocol, the IEEE 802.3 Ethernet frame format, and the IEEE 802.3 frame size. 10 Gigabit Ethernet is full duplex, just like full-duplex Fast Ethernet and Gigabit Ethernet; therefore, it has no inherent distance limitations. Because 10 Gigabit Ethernet is still Ethernet, it minimizes the IT manager's learning curve by maintaining the same management tools and architecture.

Because almost all network traffic today starts out as Ethernet and Internet Protocol (IP) traffic, building Ethernet networks with the next step up in speed will be the easiest way to scale enterprise and service-provider networks. A fundamental rule of building switched networks is that a faster technology is always needed to aggregate multiple, lower-speed segments. As the density and the number of 100-Mbps segments at the edge of the network increase, 1000BASE-X and 1000BASE-T will become the uplink technology from the wiring closet to the core of the network. At the close of 2000, the Ethernet industry was shipping over 250 thousand Gigabit ports a month. 10 Gigabit is needed to aggregate these Gigabit segments. Figure 3.1.2-1 Illustrates the number of Ethernet ports sold worldwide thru 2004.

Figure 3.1.2-1 Number of Ethernet Ports Sold Worldwide 1993 - 2004



Sources: Sw 10, Sw 100, Sw 1000: Dell'Oro Group,
Sw 10,000: Gartner Group Dataquest, Cisco Projections

In short, for enterprise LAN applications, 10 Gigabit Ethernet will enable network managers to scale their Ethernet networks from 10 Mbps, 100 Mbps, or 1000 Mbps to 10,000 Mbps, while leveraging their investments in Ethernet as they increase their network performance. For service provider metropolitan and wide-area applications, 10 Gigabit Ethernet will provide high-performance, cost-effective links that are easily managed with Ethernet tools.

10 Gigabit Ethernet will be a cost-effective means of building 10-Gbps links. The reasons for this are two-fold. First, there is the design philosophy of the Ethernet industry, which assumes high-volume manufacturing and low-cost design. In fact, the Task Force adopted as a design goal the objective to develop 10 Gigabit Ethernet interfaces that would offer ten times the performance at three to four times the cost of the previous generation of Ethernet.

Because the whole industry, from chipset vendors and optical components manufacturers up the value chain to systems vendors, participated in the standards process, the 802.3 Ethernet interfaces are very well defined and can be implemented with available technology. This process enables intense market competition at every stage of the value chain, which lowers the costs of components and subsystems, and lowers the costs of the systems that are available to the IT managers who are the end customers. This process also means that most of the complexity of the encoding schemes and electronic circuitry becomes embedded in merchant silicon, which lowers costs and increases competition among vendors. The contribution of Ethernet to technical innovation, competition, and increasingly lower costs to final end users is evident in the traditional Ethernet cost curves witnessed with Ethernet, Fast Ethernet, and, most recently, Gigabit Ethernet. Finally, in contrast to a 10-Gbps telecommunications laser, 10 Gigabit Ethernet short links (less than 40 km on single-mode fiber) will use low-cost, uncooled optics and, in the future, vertical cavity surface emitting lasers (VCSELs), which are very low cost.

Gigabit Ethernet metropolitan networks will enable service providers to reduce the cost and complexity of their networks while increasing backbone capacity to 10 Gbps by eliminating the need to build out an infrastructure that contains not only several network elements required to run TCP/IP and data traffic but also the network elements and protocols originally designed to transport voice and video. Reduction in the number of network elements and network layers lowers equipment costs, lowers operational costs, and simplifies the network architecture. 10 Gigabit Ethernet backbone networks, be enable native 10/100/1000 Mbps Ethernet to each TMC, offering the bandwidth of the fastest public MAN services OC-3 (155 Mbps) or OC-12 (622 Mbps) with no need for the added complexity of SONET or ATM and no need for protocol conversion.

Table 3.1.2-1 10 Gigabit Ethernet Physical Media Dependent (PMD) Specifications

Table 3 Optical Transceivers for 10 Gigabit Ethernet				
PMD (Optical Transceiver)	**Fiber Supported**	**Diameter (microns)**	**Bandwidth (MHz*km)**	**Minimum Distance (meters)**
850 nm Serial 10GBASE-S	Multimode	50.0	500[1]	65
1310 nm CWDM2,3 10GBASE-LX4	Multimode	62.5	160	300
1310 nm CWDM 10GBASE-LX4	Single Mode	9.0[3,4]	N.A.	10,000
1310 nm Serial 10GBASE-L	Single Mode	9.0	N.A.	10,000
1550 nm Serial 10GBASE-E	Single Mode	9.0	N.A.	40,000

1. 500 MHz*km is the OFL bandwidth value. Rated laser bandwidth might change when the TIA FO.2 work is complete
2. CWDM: Coarse wavelength division multiplexing
3. ANSI/TIA/EIA-568-A specifies that the nominal "mode field diameter" shall be 8.7 to 10.0 microns with a tolerance of +/-0.5 micron at 1310 nm
4. N.A. Not applicable

10Gig-E equipment features include:

- Support for Ethernet Automatic Protection Switching (≤ 50 msec.)
- Cost less to replace SONET with Gig-E than to upgrade
- Baseline configuration for 2 x 10 Gbps and 12 x 1 Gbps = $15,000
- Open standards compliant
- 10X bandwidth of existing RCN
- Offers highly reliable communications
- Supports multimedia content
- Offers layer 2 and layer 3 Quality of Service (Diff-Serv)
- forwards compatibility with emerging technology
- backwards compatibility with existing technology

3.1.3 Synchronous Optical Network (SONET)

SONET is an ANSI standard for high-speed transmission of digital signals using fiber-optic technology. Officially recognized by the telecommunications industry in the late 1980's, SONET quickly gained popularity in the 1990's due to the high-speed rates, "five-nines" reliability, operations administration maintenance and provisioning (OAM&P), Quality of Service and the standardization (interoperability).

SONET systems provide interconnection to routed networks operating at American National Standards Institute (ANSI) DS-3 (44.736 Mbps) and STS-1 (51.840 Mbps) electrical data rates. SONET systems are scalable, based on multiples of the electrical STS-1 format. In addition, SONET systems allow the concatenation of multiple electrical signals to form larger payloads within a common frame. For example, concatenating three STS-1s to operate at a line rate of 155.52 Mbps would be considered as an STS-3c. On the optical side, SONET systems typically operate in multiples of the OC-3 rate (155.52 Mbps). Common SONET rates include OC-3, OC-12, OC-24, OC-48 and OC-192.

Historically, SONET requires other higher layer protocols such as Internet Protocol (IP) and Ethernet to be bridge-routed (encapsulated) in a Time Division Multiplexed (TDM) payload for distribution across the network. SONET is a "transport" technology that uses statically routed connections to deliver digital information between Network Elements (NEs). This "transport" architecture requires an additional equipment layer to support interface connection with the SONET backbone.

SONET fiber systems are architecturally diverse, and support the following protection switching schemes:

- Linear Automatic Protection Switching (1+1, 1:N)
- 2 Fiber - Uni-directional Path Switched Rings (UPSR)
- 2 & 4 Fiber - Bi-directional Line Switched Rings (BLSR)

SONET systems are required to provide Linear APS within 50 milliseconds per GR-253-CORE. UPSR and BLSR protection switching are also required to switch within 50 milliseconds for specific scenarios as defined in GR-1230-CORE. SONET systems will not recover in 50 milliseconds on a 4-fiber ring switch, as it is not clearly defined in either GR-253-CORE or GR-1230-CORE. Brand name (Alcatel, Lucent, Nortel & Fujitsu) switches typically recover from this "ring wrap" scenario within 250 milliseconds.

Provisioning of Automatic Protection Switching (APS) circuits is typically considered inefficient, since the working OC-n is protected by an empty OC-n protection circuit. Under normal circumstances, 1+1 and BLSR do not utilize 50% of the bandwidth allocated to the protection group. UPSR also operates with 50% efficiency, but is protected at the STS-n rather than OC-n level. 1:n protection typically offers one protection circuit to multiple working circuits. The downside to 1:n is the lack of protection for multiple line failures. Additionally, proprietary BLSR schemes are available where the protection circuits are used for low priority communications under non-protected operation. Should the working BLSR ring require protection, the low priority communications are dropped to provide restoration to the working traffic.

Linear APS supports point-to-point configurations, whereas UPSR and BLSR support ring topologies. SONET systems operate at the data link layer, and utilize the K1 and K2 bytes for protection switching coordination between the near and far end SONET terminals. Fiber optic cable distribution requires path diversity in the networks architecture to ensure fault tolerance and signal recovery upon fiber cut.

OAM&P associated with SONET systems requires specialty knowledge which, is more common within the telecommunications field rather than by stakeholder ITS or Information Technology (IT) staffing. SONET equipment requires manual provisioning of each circuit to establish end-to-end communications across the Wide Area Network (WAN). A SONET terminals craft interface typically uses a TL-1 based syntax (more recently Windows) as an interface, which is used to statically provision communications circuits and cross-connections within the switch. It is important to recognize that all end-to-end communication paths require manual provisioning. SONET equipment requires each NE to be provisioned in software for equipped hardware modules, supported STS-n and OC-n circuits and cross-connects where applicable. None of the provisioning is performed automatically by the system. Furthermore, provisioning SONET equipment using the TL-1 language requires that maintenance personnel acquire telecommunications skills, usually from the vendor.

SONET architectures require that all Network Elements (NEs) are tightly synchronized (stratum 3e or better). SONET systems are susceptible to timing loops and require external stratum synchronization at each multiplexer within the network. In fact, synchronization within SONET is so important that systems implement internal timing reference boards to keep the system operational should external synchronization be lost (fail).

SONET transport systems are extremely reliable, but expensive. Cost increases directly with increases in bandwidth. Communications bandwidth associated with SONET interfaces has scaled from OC-3 operating at 155 Mbps to OC-768 operating at 40 Gbps. Even though SONET capacities continue to increase upwards of OC-768, a number of major telecommunications providers have reached end of lifecycle support for their products.

Since SONET operates as a data link (layer 2) protocol, there is no method for supporting layer 3 Quality of Service (QoS) mechanisms such as Diff-Serv or Int-Serv within the network. Internet Protocol based QoS mechanisms are required to be incorporated at network switches/routers at the edge of the SONET network. QoS is fundamentally important to the delivery of IP voice and video signal distribution.

SONET equipment features include:

- SONET (recovery $\leq$ 50 msec.)
- Cost = $100,000 + (for OC192)
- Open standards compliant
- 10X bandwidth of existing RCN
- Offers highly reliable communications
- Supports multimedia content
- Offers layer 2 Quality of Service
- forwards compatibility with emerging technology

3.1.4 Asynchronous Transfer Mode (ATM)

Asynchronous Transfer Mode is an international standard for high-speed digital communications developed in the mid-1980s. ATM technology emerged as a result of the Bellcore Integrated Digital Services Network (ISDN) initiative supported by the Exchange Carrier Standards Association (ECSA). Because of the delay in developing ATM standards, an ATM Forum was formed and telecommunications equipment manufacturers endeavored to develop ATM standards. Bellcore then got back into the ATM standards and developed a number of standards as appropriate to Exchange Carriers. These include standards such as GR 1113 (ATM Adaptation Layer, GR 2845 (ATM Network and Element Management) and GR 2847 (ATM Service Access Multiplexing) all now supported by Telcordia. It had some unique features supporting quality of service (QOS) and permanent virtual circuit (PVC) standards.

ATM is known for its dynamic bandwidth provisioning feature (i.e. allocating specific amounts of bandwidth for specific amounts of time) and also for its ability in transporting voice, video, data and multimedia over the same virtual circuit. This is made possible by ATM's use of small (53 bytes), fixed-size "cells" of data, which can be switched at speeds of 155 Mbps and greater over SONET/ATM networks. Furthermore, by defining "virtual circuits", ATM also provides quality of service for delay and sequence sensitive data such as voice and video. Developed in conjunction with the Synchronous Digital Hierarchy (SDH) standard, ATM was designed to work in conjunction with SDH (and SONET) to be the foundation for Broadband ISDN. ATM was developed to accommodate asynchronous data traffic over SONET. ATM's flexibility enables a multitude of applications such as Multimedia, Video Conferencing, Host-to-host computer links, PBX-to-PBX trunking and many others, all over the same virtual channel.

ATM endeavored to compete with Ethernet at the local area network level. Unfortunately adapting client/server equipment to ATM was expensive and ATM lost the LAN market to Ethernet. Ethernet added fiber standards and increased bandwidth from 10 Mbps to 10,000 Mbps. Ethernet was capable of competing with OC-192 SONET (10 Gbps) at a fraction of the cost. Now Ethernet is starting to replace both SONET and ATM in the telecommunications market and totally dominates the internet and digital cable television (now digital video, voice and high-speed internet) market. In other words, ATM has been also effectively been replaced by gigabit Ethernet in the MAN environment.

There are multiple reasons for the lack of continued support for the ATM standard. First, ATM uses a 53 byte cell structure. The processing overhead (cell tax) required to segment and then later re-assemble large file structures consumes otherwise useable bandwidth. ATM is not as efficient for transporting video as is Ethernet. Additionally, ATM does not support multicast; ATM supports video broadcast connections. Second, the cost of integrated SONET/ATM solutions is an order of magnitude higher than gigabit Ethernet. Third, continued vendor support for the standard is waning. This influences maintenance support and spares availability. Fourth, the technology is not widely understood, further limiting the numbers of qualified maintenance personnel that are available. Finally, ATM requires stratum 3e or better clocking at each node. ATM is susceptible to timing loops as well as pointer jitter. Excessive pointer jitter on the SONET interface causes ATM switching to drop all communications.

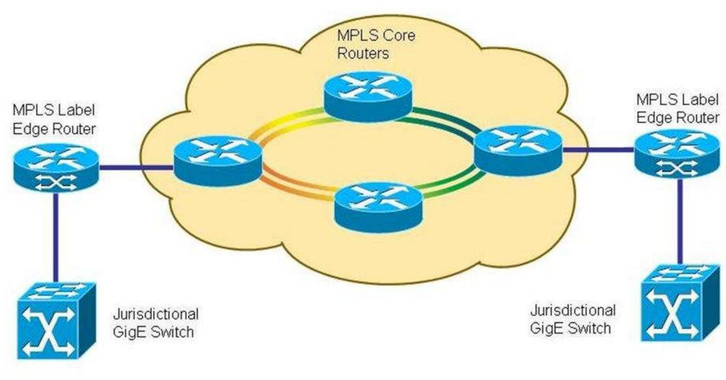
ATM/SONET equipment features include:

- SONET (1+1 or UPSR recovery $\leq$ 50 msec.)
- Cost = $150,000 +
- Open standards compliant
- 1X bandwidth of existing RCN
- Offers highly reliable communications
- Supports multimedia content
- Offers layer 3 Quality of Service

3.1.5 Multi Protocol Label Switching (MPLS)

In a MPLS network, incoming packets are assigned a "label" by a "label edge router (LER)." Packets are forwarded along a "label switch path (LSP)" where each "label switch router (LSR)" makes forwarding decisions based solely on the contents of the label. Figure 3.1.6-1 illustrates the basic MPLS architecture. At each hop, the LSR strips off the existing label and applies a new label, which tells the next hop how to forward the packet. Label Switch Paths (LSPs) are established by network operators for a variety of purposes, such as to guarantee a certain level of performance, to route around network congestion, or to create IP tunnels for network-based virtual private networks. In many ways, LSPs are no different from circuit-switched paths in ATM or Frame Relay networks, except that they are not dependent on a particular Layer 2 technology. An LSP can be established that crosses multiple Layer 2 transports such as ATM, Frame Relay or Ethernet.

Figure 3.1.6-1 Typical MPLS Architecture



The premise of multi-protocol label switching (MPLS) is to speed up packet forwarding and provide for traffic engineering in Internet protocol (IP) networks. To accomplish this, the connectionless operation of IP networks becomes more like a connection-oriented network where the path between the source and the destination is pre-calculated based on user specifics. To speed up the forwarding scheme, an MPLS device uses labels rather than address matching to determine the next hop for a received packet. To provide traffic engineering, tables are used that represent the levels of quality of service (QoS) that the network can support. The tables and the labels are used together to establish an end-to-end path called a label switched path (LSP). Traditional IP routing protocols (e.g., open shortest path first [OSPF] and intermediate system to intermediate system [IS–IS]) and extensions to existing signaling protocols (e.g., resource reservation protocol [RSVP] and constraint-based routing–label distribution protocol [CR–LDP]) comprise the suite of MPLS protocols.

Multi-Protocol Label Switching (MPLS) is a set of procedures for augmenting network layer packets with "label stacks", thereby turning them into labeled packets. It defines the encoding used by a label-switching router to transmit such packets over PPP and LAN links. It is an Ethernet Tag Switching protocol. This protocol attaches labels to IP and IPv6 protocols in the network layer, after the data-link layer headers, but before the network layer headers. It inserts a 4 or 8-byte label.

Protocol Independent Multicast (PIM). Multicast routing architecture that allows the addition of IP multicast routing on existing IP networks. PIM is unicast routing protocol independent and can be operated in two modes: dense and sparse. PIM dense mode is data-driven and resembles typical multicast routing protocols. Packets are forwarded on all outgoing interfaces until pruning and truncation occurs. In dense mode, receivers are densely populated, and it is assumed that the downstream networks want to receive and will probably use the datagrams that are forwarded to them. The cost of using dense mode is its default flooding behavior. In contrast, PIM sparse mode tries to constrain data distribution so that a minimal number of routers in the network receive it. Packets are sent only if they are explicitly requested at the RP (rendezvous point). In sparse mode, receivers are widely distributed, and the assumption is that downstream networks will not necessarily use the datagrams that are sent to them. The cost of using sparse mode is its reliance on the periodic refreshing of explicit join messages and its need for rendezvous points.

Implementation of MPLS into an ITS network would require the deployment of multiple router configurations on the network. MPLS supports Label Edge Routers and Core routers. Both types of routers would be required in the ITS architecture to ensure MPLS operation, and they are not interchangeable. Expansion of core router services requires specific devices to be connected in a particular manner, from an architectural point of view.

MPLS provides advanced features such as Virtual Permanent Network (VPN) that can include secure communications between multiple (>3) locations. This is analogous to the Virtual LAN (VLAN) found Ethernet technology.

Originally, the main benefit of MPLS was to limit the amount of time to process routing and forwarding by processing tag information only. This was to speed up the ability of protection switching, since the technology did not require use of IP lookup tables used by routing algorithms. The overall routing gain provided by use of tag switching has become mute due to Application Specific Integrated Circuit (ASIC) implementation in modern switches.

MPLS technology is not sufficient to provide connection from one equipment terminal to the next, and (from a protocol perspective) requires a physical layer to operate. Typically, MPLS technology will operate using SONET, Wave Division Multiplexing or Ethernet.

MPLS is documented in various Request For Comments as posted by the Internet Engineering Task Force (IETF). Table 3.1.6-1 provides the standards associated with the MPLS technology.

Table 3.1.6-1 MPLS Standards & Recommendations

Standards Body	**RFC**	**Title**
ITU-T	G.8110/Y.1370	SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS Ethernet over Transport aspects – MPLS over Transport aspects SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS AND NEXT-GENERATION NETWORKS Internet protocol aspects – Transport
IETF	RFC 3038	VCID Notification over ATM link for LDP
IETF	RFC 3037	LDP Applicability
IETF	RFC 3036	LDP Specification
IETF	RFC 3035	MPLS using LDP and ATM VC Switching
IETF	RFC 3034	Use of Label Switching on Frame Relay Networks Specification
IETF	RFC 3032	MPLS lable stack encoding
IETF	RFC 3031	MPLS Architecture
IETF	RFC 2917	A core MPLS IP VPN Architecture
IETF	RFC 2702	Requirements for Traffic Engineering over MPLS
IETF	RFC 2547	BGP/MPLS VPNs

While MPLS technology is considered to be mature, interoperability issues still exist between equipment vendors. This is especially true pertaining to demonstrations of IP multicast video using PIM, as observed at the 2006 MPLS World Congress.

MPLS switch features include:

- MPLS Fast Recovery ($\leq$ 50 msec.)
- Cost = $170,000/router + control plane server & software + $200k training
- Open standards compliant

- 10 to 100 times greater bandwidth of existing ADOT network
- Offers highly reliable communications
- Supports multimedia content
- Offers layer 2 and layer 3 Quality of Service (Diff-Serv)
- forwards compatibility with emerging technology

3.1.6 Resilient Packet Ring (RPR)

Resilient Packet Ring (RPR) is a transport technology specified by IEEE specification "802.17™ - IEEE Standard for Information technology: Telecommunications and information exchange between systems, Local and metropolitan area networks, Specific requirements, Part 17: Resilient packet ring (RPR) access method and physical layer specifications".

This technology provides the best of both Ethernet and SONET technologies by supporting features such as 50ms protection switching for high network availability while having a packet based transport that can utilize statistical multiplexing gain to better utilize all available bandwidth including protection bandwidth. Further, RPR provides several levels of Quality of Service (QoS) guarantees, including QoS sufficient to select a solution for support any type of TDM service transported over packets. As packets have become, by far, the most dominant traffic, RPR is, therefore, one of the most efficient transport technologies for both packet and TDM traffic services going forward.

Triple Play services include Voice, Video, and Data. There are nuances to each of these services. Voice services can include real-time voice traffic, e.g., phone call, or non real-time, streaming music distribution. Video services traditionally include streaming video distribution, e.g., Video-On-Demand. Video services can also include video teleconferencing, which is a real-time service. These differences in services require different levels of QoS from the transport mechanism in the network. RPR works well to provide all of these services due to its defined service primitives in IEEE 802.17. These service primitives are:

- Class A Service - Provides an allocated, guaranteed data rate with low end-to-end delay and jitter bound. This class has precedence over all other classes.
- Class B Service - Provides an allocated, guaranteed data rate with bounded end-to-end delay and jitter for the allocated rate. This class also provides access to unallocated bandwidth that has no guaranteed data rate or bounded delay and jitter. The primitives referring to the different used bandwidths are Class B Committed Information Rate (classB-CIR) and Class B Excess Information Rate (classB-EIR). Class B takes precedence over class C.
- Class C Service - Provides a best effort delivery with no guaranteed data rate and no bounded delay or jitter.

Table 3.1.7-1 Service classes and their quality-of-service relationships

Class of Service			Qualities of Service				Fairness Eligible
Class	**Examples of Use**	**Subclass**	**Guaranteed Bandwidth**	**Jitter**	**Type**	**Subtype**	
A	Real Time	subclassA0	Yes	Low	Allocated	Reserved	No
		subclassA1	Yes	Low	Allocated	Reclaimable	
B	Near Real Time	classB-CIR	Yes	Bounded			
		ClassB-EIR	No	Unbounded	Opportunistic	Reclaimable	Yes
C	Best Effort	--					

RPR can support multiple rates; 1G, 2.5G, and 10G are the standard rates. This allows for scaling of the technology to accommodate a growing network. 1G transport uses a Gigabit Ethernet physical layer. 2.5G transport uses a SONET OC48 physical layer. 10G uses a SONET OC-192 or 10GE physical layer.

RPR multicast video is handled by flooding the ring nodes with the video packet. The ring node that has the destination subnet will process the video to the client as a standard drop channel. This video "multicast" connection must be entered manually at the appropriate ring nodes.

Automatic protection switching associated with ring connections includes ring wrapping and span switching. All protection switching occurs within 50 msec. Service Level Agreements (SLAs) or QoS mechanisms require proper sizing of the ring bandwidth to ensure that traffic is not dropped.

RPR solutions have not been fully adopted as mainstream technology for telecommunications service providers. Multi-Protocol Label Switching (MPLS) core networks, and 10 Gig Ethernet products have overshadowed RPR offerings to date.

RPR switch features include:

- RPR (recovery $\leq$ 50 msec.)
- Cost = $100,000 + (for OC192)
- Open standards compliant
- 10X bandwidth of existing
- Offers highly reliable communications
- Supports multimedia content
- Offers layer 2 Quality of Service (QoS)
- forwards compatibility with emerging technology

3.1.7 Wide Wavelength Division Multiplexer (WWDM)

In fiber optic communications, wide wavelength division multiplexing (WWDM) is a technology, which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths (colors) of laser light to carry different signals. The optical properties associated with this technology are such that the two different wavelengths do not interfere with each other. This allows for a multiplication in capacity, in addition to making it possible to perform bidirectional communications over one strand of fiber.

These devices are available as passive optical components, which in operation are similar to a prism. This equipment configuration requires that interconnected equipment support two different wavelengths, typically @ 1310 nm and 1550 nm. The performance characteristics and operational performance for this equipment falls under the ITU-T G.671 standard, and is termed Wide WDM (WWDM). Channel spacing under ITU-T G.671 requires a minimum separation of 50 nm.

The head end equipment connecting to the passive WWDM device is responsible for providing all of the power relating to each optical carrier signal. Insertion losses associated with the passive device must be included in the optical link budget calculation for the communications path, in addition to fiber transmission and splice losses. The "active" head end equipment determines the overall communications bandwidth of the optical link. It is not uncommon for these devices to support communications rates over 1 Gbps. Point to point network architectures are the only topology supported by simple WWDM devices. Network redundancy and/or protection switching associated with passive splitter/combiner equipment is not provided, and again is a function of the head end devices. Support for QoS as related to multimedia communications is additionally the responsibility of the attached, active communications equipment.

Passive optical wavelength combiners are highly reliable devices that require little to no maintenance. WWDM devices are very rugged, supporting deployment in field cabinets. Additionally, WWDM devices are protocol agnostic and are only sensitive to the particular wavelengths used across the system. Passive WWDM equipment is typically used to reduce the number of fiber deployed to support a communications architecture. Cost associated for passive WWDM devices ranges from $1000 upwards. Figure 3.1.8-1 illustrates the typical application of a 1310/1550 nm WWDM deployment over single mode fiber.

Figure 3.1.8-1: Typical Application of a 1310/1550-nm WWDM

3.1.8 Coarse Wavelength Division Multiplexer (CWDM)

With a capacity greater than WWDM, coarse wave division multiplexing (CWDM) allows eighteen or less wavelengths, to be evenly distributed between 1270 nm and 1610 nm. In order to reduce cost, CWDMs use un-cooled lasers operating with a channel spacing of 20 nm and a relaxed tolerance of ± 3 nm. The wide spacing accommodates un-cooled laser wavelength drifts that occur as ambient temperature varies. The un-cooled laser drifts about ±0.06 nm/°C.

Coarse WDMs perform two functions. First, they filter the light, ensuring only the desired wavelengths are used. Second, they multiplex or de-multiplex multiple wavelengths, which are used on a single fiber link (Figure 3.1.8-1). In the multiplex operation, the multiple wavelength bands are combined (i.e. *muxe*d) onto a single fiber. In a demultiplex operation, the multiple wavelength bands are separated (i.e. *demuxe*d) from a single fiber. Insertion loss for an eight channel device is about 2 dB per end. The passband is around 13 nm wide at the -0.5 dB loss point.

Figure 3.1.8-1 CWDM Multiplexing Used for Uni-directional & Bi-directional Communications

8 λ Uni-directional CWDM (1 Fiber)

8 λ Bi-directional CWDM (1 Fiber)

The impact of an optical fiber on CWDM transmission cannot be ignored. Until recently, CWDM over standard single-mode fiber typically transmitted eight to perhaps 12 wavelengths due to excessively high attenuation in the “water peak” region (1383 nm). Figure 3.1.8-2 illustrates the CWDM band in relation to the SMFO water peak occurring at approximately 1400 nm. The CWDM wavelengths are defined by the International Telecommunications Union; reference ITU G.694.2 for the ITU CWDM Wavelength Grid. Table 3.1.8-1 provides the center wavelengths used for CWDM, as specified by the ITU-T.

Figure 3.1.8-2 CWDM channel allocations per ITU G.694.2 with respect to SMFO "water" peak at 1400 nm.

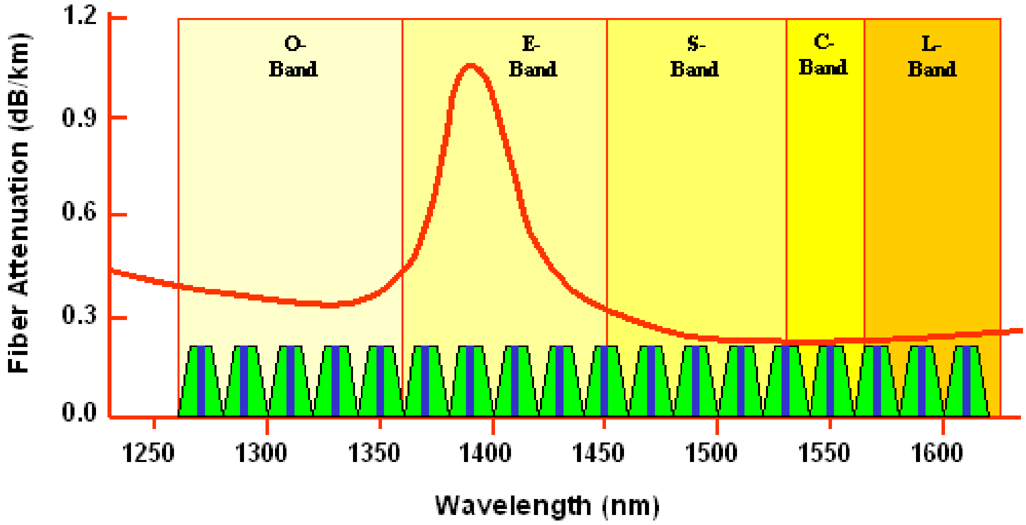


Table 3.1.8-1 provides the center wavelengths used for CWDM, as specified by ITU-T G.694.2.

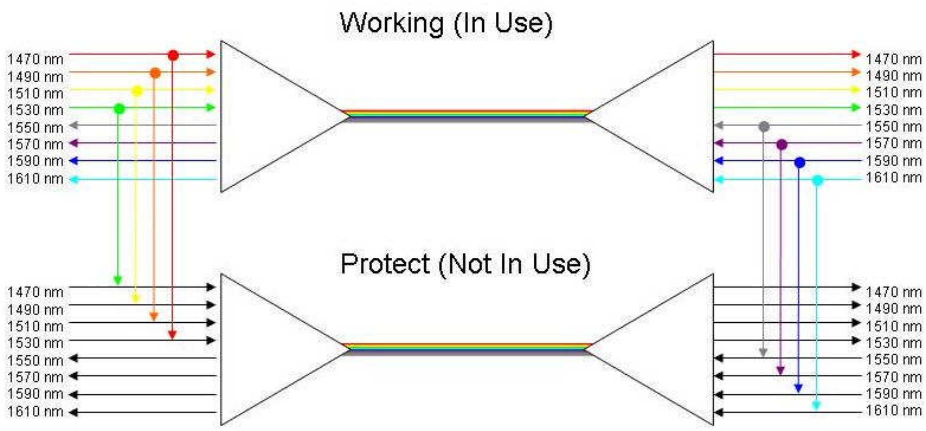
Nominal central wavelengths (nm) for spacing of 20 nm	
1270	1450
1290	1470
1310	1490
1330	1510
1350	1530
1370	1550
1390	1570
1410	1590
1430	1610

Note: The CWDM Grid lists eighteen center wavelengths, from 1270 nm to 1610 nm, at 20 nm spacing.

Another important aspect related to the insertion loss is the channel-by-channel loss profile. For many system applications, it is undesirable for different wavelength channels of data to attenuate differently along a transmission line. Thus, uniform insertion loss among channels is typically required.

Bi-directional CWDM devices that support protection switching algorithms such as 1+1 or UPSR, require active electronics to support the bridging and connection of communications to the protect circuit. This may be performed in either the photonic or electrical domain. Additional optical and electronic circuits add directly to the cost of the device. Figure 3.1.8-3 illustrates the concept behind a 1+1 protection switching scheme.

Figure 3.1.8-3 Illustration of a conceptual 1+1 protection group for CWDM communications



8 λ Bi-directional CWDM (2 Fiber in 1+1 Configuration)

CWDM implementations can also be achieved using passive optical devices. These passive optical multiplexers represent a significant reduction in the overall cost of CWDM equipment, but also limit the overall functionality. Passive CWDM devices only offer access "on" and "off" the fiber cable. These devices, as illustrated in Figure 3.1.8-4, only provide multiplexing access to the backbone fiber. From an architecture standpoint, passive CWDM devices only support point-to-point topologies.

Figure 3.1.8-4 Example of a passive 8 λ CWDM multiplexer

To re-iterate, passive optical devices do not provide any intelligent network functions, such as support for QoS or IP multicast functionality. Passive CWDM multiplexers do not provide protection switching. Additionally, passive CWDM devices typically require the use of GBIC LASER technology, which provides the proper wavelength for operation across backbone fiber. The GBICs, as illustrated in Figure 3.1.8-5, are manufactured to provide the LASER light in accordance with the ITU center frequencies, and can simply be inserted into equipment that supports the GBIC interface. It is important to recognize that the

GBIC modules are installed into the connecting devices, not in the CWDM multiplexer. GBIC technology is commonly deployed in GigE switches.

Figure 3.1.8-5 Examples of GBIC LASERs for use with CWDM systems.

CWDM multiplexer features include:

- 1+1 Architecture (recovery $\leq$ 50 msec.)
- Cost = 8 ג Active System for $50,000 +
- Cost = 8 ג Passive System for $15,000 +
- Open standards compliant (protocol agnostic)
- 10x bandwidth of existing
- Offers highly reliable communications
- Does <u>not</u> support IP multicast
- “Transport” technology only, offers <u>no</u> QoS
- Forwards compatibility with emerging technology
- Requires careful design, install & verification of OSP fiber
- Supported configurations include both active and passive models

3.1.9 Dense Wavelength Division Multiplexer (DWDM)

Wavelength Division Multiplexing is a high-speed digital communication technology that simultaneously transports optical signals of different wavelengths over a single strand of fiber-optic cable. Developed as a next generation transport technology, WDM takes over where SONET/SDH leaves off. WDM creates different channels by dividing a frequency band into smaller bands. The latest version of WDM, Dense WDM (DWDM), achieves higher capacity by dividing a wavelength-band into even more channels. The latest DWDM equipment offers capacities including 40 ג channels @ 40 Gbps = 1.6 Tbps and 160 ג channels @ 10 Gbps = 1.6 Tbps.

The difference between CWDM and DWDM is fundamentally one of only degree. DWDM spaces the wavelengths more closely than does CWDM, and therefore has a greater overall capacity. DWDM technology channel spacing is defined in the ITU-T G.694.1 specification. ITU-T G.698-1 defines Multichannel DWDM applications with single channel optical interfaces (pre-published). Table 3.1.9-1 Provides the details pertaining to the DWDM frequency grid per ITU-T G.694.1

Table 3.1.9-1 ITU-T G.694.1 DWDM Frequency Grid

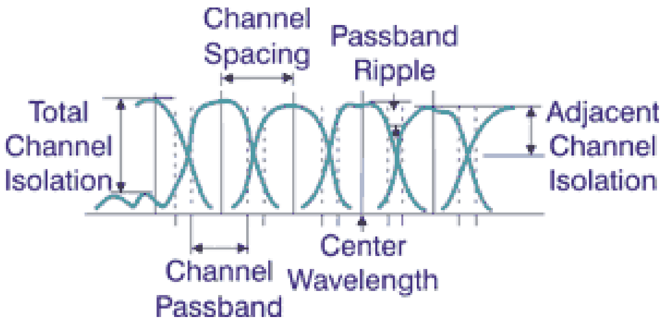
Nominal central frequencies (THz) for spacings of:				Approximate nominal central wavelengths (nm)
12.5 GHz	**25 GHz**	**50 GHz**	**100 GHz and above**	
195.938				1530.04
195.925	195.925			1530.14
195.913				1530.24
195.9	195.9	195.9	195.9	1530.33
195.8875				1530.43
195.875	195.875			1530.53
195.8625				1530.63
195.85	195.85	195.85		1530.72
195.8375				1530.82
195.825	195.825			1530.92
195.8125				1531.02
195.8	195.8	195.8	195.8	1531.12
195.7875				1531.21
195.775	195.775			1531.31
195.7625				1531.41
195.75	195.75	195.75		1531.51
195.7375				1531.6
195.725	195.725			1531.7
195.7125				1531.8
195.7	195.7	195.7	195.7	1531.9
195.6875				1532
195.675	195.675			1532.09
195.6625				1532.19
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
193.2375				1551.42
193.225	193.225			1551.52
193.2125				1551.62
193.2	193.2	193.2	193.2	1551.72
193.1875				1551.82
193.175	193.175			1551.92
193.1625				1552.02
193.15	193.15	193.15		1552.12
193.1375				1552.22
193.125	193.125			1552.32
193.1125				1552.42
193.1	193.1	193.1	193.1	1552.52
193.0875				1552.62
193.075	193.075			1552.73
193.0625				1552.83
193.05	193.05	193.05		1552.93
193.0375				1553.03
193.025	193.025			1553.13

193.0125				1553.23
193	193	193	193	1553.33
192.9875				1553.43
192.975	192.975			1553.53
192.9625				1553.63
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
184.775	184.775			1622.47
184.7625				1622.58
184.75	184.75	184.75		1622.69
184.7375				1622.8
184.725	184.725			1622.91
184.7125				1623.02
184.7	184.7	184.7	184.7	1623.13
184.6875				1623.24
184.675	184.675			1623.35
184.6625				1623.46
184.65	184.65	184.65		1623.57
184.6375				1623.68
184.625	184.625			1623.79
184.6125				1623.9
184.6	184.6	184.6	184.6	1624.01
184.5875				1624.12
184.575	184.575			1624.23
184.5625				1624.34
184.55	184.55	184.55		1624.45
184.5375				1624.56
184.525	184.525			1624.67
184.5125				1624.78
184.5	184.5	184.5	184.5	1624.89

DWDM channel spacing governs system performance; 50 GHz and 100 GHz outline the standards of ITU channel spacing. Currently, 100 GHz is the most commonly used and reliable channel spacing. This spacing allows for several channel schemes without imposing limitations on available fiber amplifiers. However, channel spacing depends on the system’s components.

Channel spacing is the minimum frequency separation between two multiplexed signals. An inverse proportion of frequency versus wavelength of operation calls for different wavelengths to be introduced at each signal. The optical amplifiers bandwidth and receivers ability to discriminate between two close wavelengths sets the channel spacing. Figure 3.1.9-1 illustrates the typical DWDM specifications.

Figure 3.1.9-1 - Typical Optical Characteristics for DWDM Channels



DWDM communications systems are typically provided as modules within a communications chassis. These devices can provide either unidirectional or bidirectional DWDM communications. Figure 3.1.9-2 illustrates a DWDM link operating using a unidirectional mode, and Figure 3.1.9-3 illustrates equipment deployment using a bidirectional method.

Figure 3.1.9-2 illustration of a DWDM unidirectional communications link.

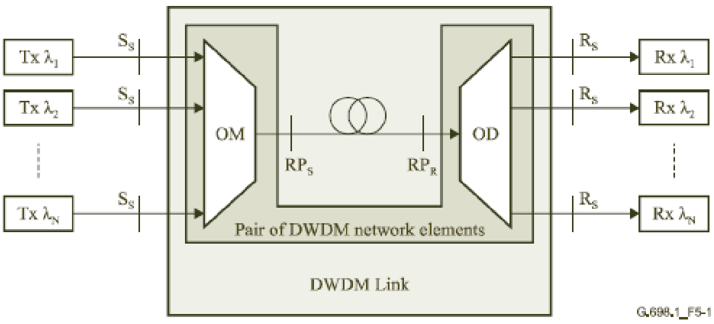
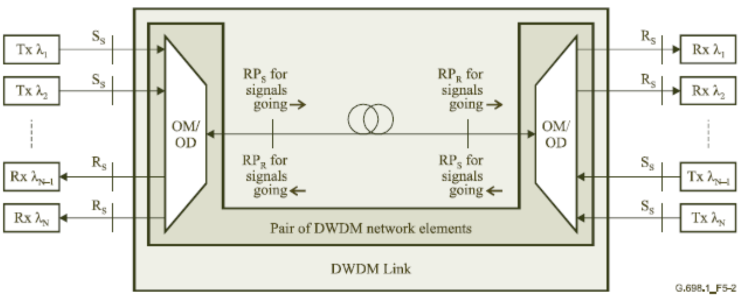


Figure 3.1.9-3 illustration of a DWDM bidirectional communications link.



Modern DWDM is based on advances made in optical amplifier technology such as Erbium Doped Fiber Amplifiers (EDFAs) and Raman Amplifiers. These amplifier technologies extended the number operational DWDM channels, while preserving a high degree of linearity between the different wavelengths.

Because these additional wavelengths could be used, DWDM revolutionized data transmission technology by increasing the capacity signal of embedded fiber. DWDM equipment can provide up to two orders of magnitude greater in transmission capacity over single gigabit technologies, and is the most obvious advantage of DWDM technology. As demands change, more capacity can be added at cost of the equipment, and existing fiber plant investment is retained.

Important components for DWDM systems are the DWDM multiplexers, transmitters (fiber amplifiers), receivers (fiber filters), and DWDM demultiplexers. These components, along with conforming to ITU channel standards, allow a DWDM system to interface with other equipment and to implement optical solutions throughout the network.

At the DWDM transmitter, optical lasers are designed to operate in a closed loop manner, where the output is continually adjusted to keep the output frequency stable. This negates the effects of frequency drift due to temperature change. DWDM equipment requires a high degree of linearity with respect to the power output of individual wavelengths.

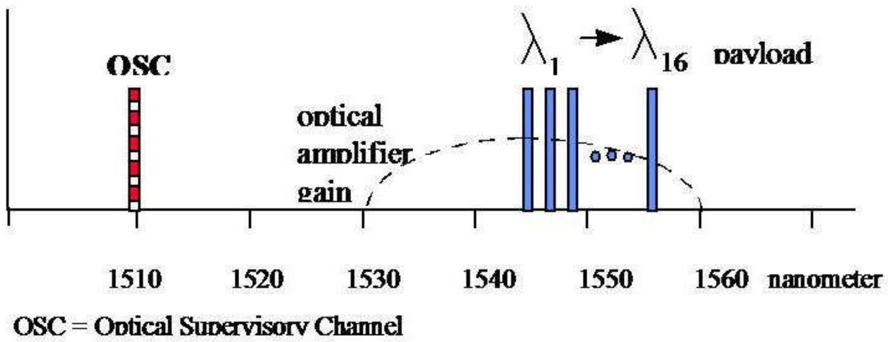
On the receive side, equipment designs require narrow passbands, usually 0.4 nm wide, with steep roll-off to reject adjacent channels, and stable operation over increased temperature. Demultiplexers need to eliminate crosstalk and channel interference. DWDM equipment requires tight tolerances with respect to band pass filtering to support channel isolation between adjacent wavelengths.

Per ITU specification, DWDM systems may be implemented in such a manner that the center frequencies can be evenly or un-evenly spaced to support operation of multiplexed link. The random selection of operational frequencies from a vendor can make the equipment lack interoperability with other vendors. Additionally, Use of DWDM wavelengths does not necessarily indicate that interoperability will be achieved. Manufacturers can option to build devices using some, but not all of the specified wavelengths to support operations for that particular equipment brand. The selection of different wavelengths by other vendors will only provide interoperability on the wavelengths specified. It is important that the vendor pass conformance with ITU specifications, as well as product demonstration of interoperability with competing manufacturer's equipment.

Protection schemes implemented on DWDM equipment and in the network designs are at least as robust as those built into SONET. DWDM equipment supports both ring and linear topologies. Essentially, DWDM may save fiber overall when considered for deployment in a MAN/WAN environment, but the technologies operation requires a working and protect pair of fibers to support protection switching. This means that the protect fiber is not typically used, except under fail over situations.

DWDM systems use out an out of band Optical Supervisory Channel (OSC), which provides communications on a separate wavelength to support network management reporting and remote administration. Figure 3.1.9-4 illustrates the relative positioning of the OSC with respect to the other communications channels used in the DWDM scheme.

Figure 3.1.9-4 Relative wavelength position of OSC channel with respect to other communications channels used in the DWDM scheme.



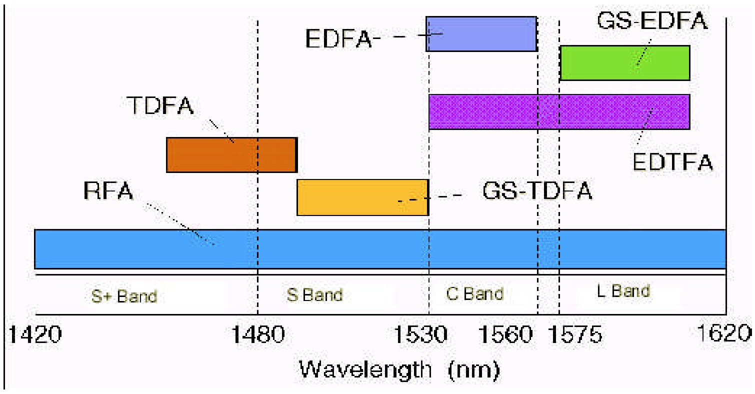
DWDM LASERs have recently been produced in GBIC modules. The impact is a overall reduction in the cost of DWDM equipment and potential for greater vendor interoperability. Because DWDM systems handle information optically rather than electrically, it is imperative that long-haul applications do not suffer the effects of dispersion and attenuation.

Other Optical Amplifiers

Silicon optical amplifiers (SOAs) are shown in Figure 3.1.9-5. These include rare-earth elements to make rare-earth-doped fibers into optical amplifiers such as:

- Tellurium (a compound of Tellurite and Oxygen [TeO_2])
- Thulium (commonly a compound of Thulium and Fluoride [TmF_3])
- Most amplifiers are still experimental and include:
- EDFA: Erbium-doped fiber amplifier (1530–1565 nm)
- GS-EDFA: Gain-shifted EDFA (1570–1610 nm)
- EDTFA: Tellurium-based gain-shifted TDFA (1530–1610 nm)
- GS-TDFA: Gain-shifted thulium-doped fiber amplifier (1490–1530 nm)
- TDFA: Thulium-doped fluoride-based fiber amplifier (1450–1490 nm)
- RFA: Raman fiber amplifier (1420–1620 nm or more)

Figure 3.1.9-5: Optical Amplifiers



DWDM equipment features include:

- DWDM (recovery $\leq$ 50 msec.)
- Cost = $150,000 (320 Gbps Ring Configuration w/16 channels)
- Cost = $16,000 (OC192/10 GigE module)
- DWDM configurations: Ring and Linear
- ADM configuration: 1+1
- Open standards compliant – protocol agnostic
- Supports operation of multiple OC-n, Gig-E and 10Gig-E channels onto same fiber
- 100X bandwidth of existing RCN
- Offers highly reliable communications
- Does <u>not</u> support IP multicast
- "Transport" technology only, offers <u>no</u> QoS
- Forwards compatibility with emerging technology
- Requires dispersion compensated fiber to support operation
- Requires careful design, install & verification of OSP fiber
- Supports network management by using an additional multiplexed channel between Network Elements (NEs)

3.1.10 SONET Metro/Edge

SONET's hardware implementation by equipment manufacturers continues, resulting in the emergence of many hybrid equipment platforms. Specifically, a number of smaller manufacturers targeted the "Metro-Edge" add-drop multiplexer market. SONET "Metro/Edge" switches emerged on the market around Y2K. Typically, a SONET multiplexer is combined with the functions of a router, Ethernet switch, ATM switch or all the above. More recently, equipment configurations also include such features as MPLS, RPR and DWDM.

These devices are capable of supporting a variety of circuit types into the ADM, including Ethernet. These devices combined the normally external, but required bridge/router capability directly into the front end of the SONET multiplexer.

ADM interfaces to SONET terminals are now available supporting standards such as T1, T3, STS-1, Fast Ethernet, GigE and ATM.

Not only are diverse interface standards being provided as an integrated bridge-router front end to SONET, but also integrated Digital Access Cross-connect (DACs) functionality is now supported. These devices support many different configurations, which makes it difficult to guarantee support from multiple vendors, as related to long term equipment maintenance. For example, fiber backhaul from these devices also includes Dense Wave Division Multiplexing (DWDM) up to 100 Gbps, with 1+1 or UPSR protection switching (50 msec.). These protection switching architectures are point to point, and do not provide the level of redundancy as required for a regional ITS network deployment.

While a number of these devices support Gigabit Ethernet, they typically fail to provide layer 3 QoS. This has a direct impact on the ability to support IP multicast video across the network architecture. Additionally, the concept of SONET Metro/Edge solutions has been a buffet of networking options to support claims of connection with many different protocols. Interoperability amongst vendors requires proof of equipment operation in an interoperability laboratory prior to purchase.

SONET Metro/Edge equipment features include:

- SONET (1+1 or UPSR recovery $\leq$ 50 msec.)
- Cost = 50k + (much higher for DWDM, MPLS)
- Open standards compliant
- 10X bandwidth of existing RCN
- Offers highly reliable communications
- Supports multimedia content
- Offers layer 2 Quality of Service
- forward compatibility with emerging technology
- backward compatibility with existing technology

3.1.11 Generalized MPLS/Reconfigurable Optical Add Drop Multiplexers (ROADM)

Generalized MPLS (GMPLS) extends MPLS to provide the control plane (signaling and routing) for devices that switch in any of these domains: packet, time, wavelength, and fiber. This common control plane promises to simplify network operation and management by automating end-to-end provisioning of connections, managing network resources, and providing the level of QoS that is expected in the new, sophisticated applications.

GMPLS is a proposed IETF standard designed to simplify the creation and management of IP/MPLS services over optical networks. The standard would create a single control plane that extends from IP at Layer 3 right down to the optical transport level at Layer 1.

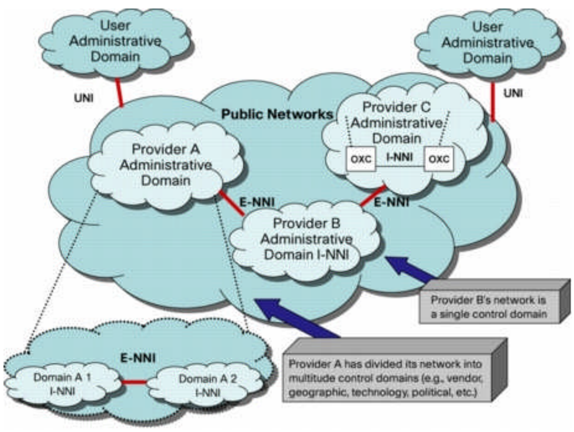
Since service providers first began transporting IP traffic, an extremely complex, multilayered overlay architecture has evolved to do the job of carrying IP traffic over networks that were originally designed to support voice and fixed circuits technology. Yet today, with the rapid growth of IP traffic promoted by the rapid increase in broadband access, new applications, and new services, these complex overlay networks cannot support rapid service provisioning, dynamic bandwidth management, and flexible service creation to meet user demand.

GMPLS was developed as a unified control plane that extends intelligent IP/MPLS connections from Layer 2 and Layer 3 all the way to Layer 1 optical devices. Unlike MPLS, which is supported mainly by routers and switches, GMPLS can also be supported by optical platforms, including SONET/SDH, optical cross-connects (OXCs), and DWDM. GMPLS therefore allows an entire network infrastructure-from access network to core networks-using a common control plane. Establishing a path to enable optical elements within the transport network to become peers of the routers in the IP network and being able to autoprovision wavelengths driven by the IP control plane can translate to significant savings in operational costs because the networks can cooperatively handle fault correlation in real time.

Additionally, service provisioning can also be greatly accelerated, since the control plane extends to the different types of equipment. The problem rests in the fact that the network will still require manual provisioning of equipment. This is especially true for the inclusion of SONET, CWDM and DWDM equipment types.

S-GMPLS internetworks with the Automatically Switched Optical Network (ASON) architecture (G. 8080) developed by the ITU. ASON, shown in one of many possible implementations of global optical connection control in Figure 1, is a dynamic signaling-based, policy-driven control solution over optical and SONET networks through a distributed or partially distributed control plane that provides auto-discovery and dynamic connection setup.

Figure 3.1.11-1 ASON Architecture for Global Optical Connection Control



ASON enables improved support for end-to-end provisioning, rerouting, and restoration; new transport services, including bandwidth on demand; rapid service restoration for disaster recovery; switched connections in a private network; and support for a wide range of narrowband and broadband signaling types. The user network interface (UNI) is responsible for signaling operations between end-user and service provider administrative domains. The external network-to-network interface (E-NNI) provides multi-control domain operations for a single service provider and multi-control domain operations between different service providers. The visibility of the inner structure of the administrative domain is controlled by the policy of the service provider. The internal network-to-network interface (I-NNI) provides intra-control domain operation. Finally, the OXC system is an electrical or photonic matrix for switching wavelengths.

Table 3.1.11-1 Comparison of GMPLS Models

ASON Framework	**Signaling**	**Routing**	**Service**
OIF-UNI	O-UNI	No	Inter service provider (wholesale), service provider to customer
Peer	RSVP-TE	OSPF-TE	Intra service provider
S-GMPLS	RSVP-TE	OSPF-TE	Intra service provider, inter service provider
IETF Overlay (GMPLS-UNI)	RSVP-TE	No	Service provider to customer

GMPLS is an attempt by telecommunications to preserve investment in legacy SONET, DACS, OXC, CWDM and DWDM equipment. All of these devices support TDM services at some level. GMPLS is a complex specification, with options for many different types of equipment. Again, GMPLS provides an enhanced control plane (maintenance capability) when compared to MLPS.

GMPLS equipment features include:

- GMPLS Fast Recovery ($\leq$ 50 msec.)
- Cost = $400,000/router + $200,000/control plane server & software + $300k training
- Open standards compliant
- 100 times greater than bandwidth of existing ADOT network
- Offers highly reliable communications
- Supports multimedia content
- Offers layer 2 and layer 3 Quality of Service (Diff-Serv)
- forwards compatibility with emerging technology

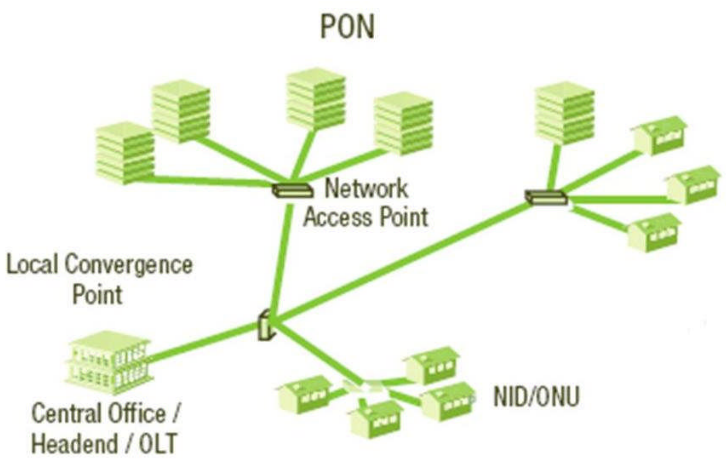
- backwards compatibility with existing technology

3.1.12 Passive Optical Network (PON)

Fiber-To-The-Home (FTTH) is simply the 100 percent deployment of optical fiber in the access network. It is commonly deployed in two specific configurations. In the first, fiber is dedicated to each user in the access network. This is referred to as a tree network, built on point-to-point connections. In the second, fiber is shared (via a passive CWDM optical splitter) among a set amount of users, and is referred to as a PON.

A PON consists of a central office node Optical Line Termination (OLT) at the service providers office and a number of Optical Network Units (ONUs) near end users. The OLT provides the interface between the PON and the backbone network, while the ONU provides the service interface to the end user. A PON is a converged infrastructure that can carry multiple services such as voice (plain old telephony service or voice over IP), data, video, and/or telemetry, in that all of these services are converted and encapsulated in a single packet type for transmission over the PON fiber. Figure 3.1.12-1 illustrates the PON architecture.

Figure 3.1.12-1 Example of a PON Network Architecture



A passive optical network (PON) is a system that brings optical fiber cabling and signals all or most of the way to the end user. Depending on where the PON terminates, the system can be described as FTTx. The passive simply describes the fact that optical transmission has no power requirements or active electronic parts once the signal is going through the network. To understand how PONs work it is best to go back to basics. Essentially, carriers want to connect each customer site with a wavelength of light, but they want to avoid having to dedicate a fiber to every wavelength. PONs address this issue by bundling together multiple wavelengths (up to 32 at present) so they can be carried over a single access line from the carrier's central office (CO) to a manhole or controlled environmental vault close to a cluster of customer sites. At that point, the wavelengths are broken out and each one is steered into a different short length of fiber to an individual site. A different scheme is used for collecting traffic traveling in the opposite direction - from user sites to the CO. In this case, each site is given a specific time slot to transmit, using a polling scheme similar to the one used in old networks.

Despite their advantages, PONs face significant obstacles on the road to success. The fact that PONs share bandwidth among multiple subscribers lowers service costs and helps carriers efficiently amortize the equipment and operations expenses. However, any amount of upstream bandwidth transmitted over a PON will be divvied up among the number of users at the customer site. Addition of splitters to links that have already been split leads to lowering of the final available bandwidth. Also, the fact that PONs do not regenerate or convert optical signals mid-network makes them cheaper, but it also limits their reach. Without regeneration, light signals lose power quickly, consequently losing transmission capability.

Additionally, all forms of PON fall under the same general network architecture, the tree. The tree network architecture does not allow for fault tolerance or protection switching between the central location and field subscriber locations. If a fiber cut occurs between the head end site and the first field splitter, all communications with the field will be lost. It is due to this architecture that makes PON technology unsatisfactory for deployment supporting a regional ITS architecture.

3.1.11.1 IEEE 802.3ah GE-PON or EPON - Gigabit Ethernet PON

GE-PON, also called EPON, is deployed widely in Japan and provides for a symmetrical 1.0 Gbps data rate in both directions, upstream and downstream. It is the first gigabit PON technology to achieve high volume deployment.

One of the most important advantages of GE-PON is the use of native Ethernet transport protocols. Low-cost asynchronous Ethernet has been deployed in the extended data network for years and there are significant economies of scale associated with gigabit Ethernet components such as optical interfaces. The asynchronous nature of Ethernet enables Ethernet-based network equipment to be much lower cost than comparable clock-synchronous ATM or SONET-based equipment.

IEEE 802.3ah - Key Facts

- Ratified by the IEEE in June of 2004
- Combines Ethernet transport protocols with point to multipoint PON network topologies
- Also called Ethernet in the First Mile or EFM
- 1.0 Gbps symmetrical upstream and downstream bandwidth

- Includes mechanisms for network Operations, Administration and Maintenance (OAM)
- Supports Class of Service (CoS) operation for time-sensitive transport of data payloads such as video where video frames must be delivered in sequence and in time to prevent visible glitches
- Supports TDM using circuit emulation services
- Supports voice services with Voice over IP (VoIP)

3.1.11.2 ITU-T G.984 GPON - Gigabit PON

GPON has received a lot of attention since the ITU introduced the ITU-T G.984 recommendation in 2003. But the recommendations are still in flux with details still being updated. As a result, GPON is not yet widely deployed. GPON is based on the previous ITU BPON standard but has many similarities to GE-PON. Introduced in 2003 as ITU-T G.984, GPON uses a new native Generic Encapsulation Method (GEM) transport layer that supports multiple "non-native" transport protocols including ATM, Ethernet, and TDM. The original intention was to broaden support and market acceptance by supporting multiple protocols, but the effect has been to add complexity to those systems not requiring additional protocol support. A key characteristic is the 2.5 Gbps downstream data rate and the 1.25 Gbps upstream data rate. GPON operates in a very similar fashion to GE-PON when supporting Ethernet as its primary transport protocol. But since Ethernet, gigabit Ethernet and 10Gb Ethernet do not support a 2.5 GHz clock rate, unlike GE-PON, GPON does not benefit from the availability of low-cost Ethernet optical components.

ITU-T G.984 - Key Facts

- Recommendation from ITU-T in January of 2003, revisions in process
- Uses Generic Encapsulation Method (GEM) protocol layer to support Ethernet, ATM and TDM over point to multipoint PON network topologies
- 1.25 Gbps upstream and 2.5 Gbps downstream bandwidth
- Includes mechanisms for network Operations, Administration and Maintenance (OAM)
- Supports Class of Service (CoS) operation for time-sensitive transport of data payloads
- Supports TDM using circuit emulation services or transport over GEM
- Supports voice services with Voice over IP (VoIP)

4.0 Critical Interoperability Factors

Network architecture, integration of communications standards and interoperability are key to successful implementation of an ITS regional communications network. A number of technological hurdles exist in moving forwards with the concept, and further, design of a network capable of supporting multimedia center-to-center communications.

Overall trends in telecommunications are the migration from time division multiplexed strategies in favor of Internet Protocol (IP) packet switched networks. Associated with this trend, is the adoption and evolution of communications standards and their respective adoption in the consumer marketplace. An appropriate technology solution to meet the needs for a regional network must address these issues, and provide a clear roadmap towards implementation.

Evolution of the IP protocol is currently underway. Most networks currently utilize IPv4, but a migration supported by upcoming federal mandates includes a growing minority of implementations using IPv6. Any solution that is recommended must include the capability of supporting the upgrade of this key technology. A regional solution must take into account the operational status of supported edge networks. Should the regional network provide the capability to support L3 QoS mechanisms, then the implementation needs to support both IPv4 and v6 capability as a native feature set. Should the technology proposed for a regional network be based on “transport” technology, that is protocol agnostic, then the requirement for IP protocol compatibility rests with supporting edge equipment. In the case of a regional ITS network, this could become the responsibility of the ITS network interface provided by local jurisdictions.

Secondly, multicast video standards and support for Application Programming Interface (API) software is critical in supporting regional capabilities. This will require a common method for the identification of video sources, such as CCTV and VIDS, as well as the ability to request and display at locations geographically dispersed within the region. Additional constraints associated with multicast technology include the use of common methodology and protocols. Network locations where multicast is intended require network equipment to respond in the same manner. For example, if the Protocol Independent Multicast (PIM) – sparse mode is used, rendezvous points (switches) will need to be identified on the network architecture to support the multicast feature. Rendezvous points may need to occur not only on the regional network layer, but on the jurisdictional ITS network layer as well. This leads to implications of common network equipment types and protocol utilization.

Third, video codec selection is a key factor in supporting multi-jurisdictional communications. A number of IP video codecs are currently available and some are open standards based, while others are proprietary. Selection of a common video codec standard should be based on an open protocol. Good examples of open video codecs would be MPEG2, MPEG4 (ASP) and MPEG4 (AVC). Codec technology should similarly support migration to IPv6, and use open control protocols for PTZ operations.

Finally, use of a common network technology that supports both jurisdictional and regional communications greatly simplifies overall deployment from an interoperability standpoint. Additionally, common technology simplifies the overall control plane, which is responsible for supporting network configuration and end-to-end management. Common equipment leads to greater interoperability and reduction in maintenance cost associated with long term OAM&P of the network.

5.0 Technology Tradeoff Matrix

Based on the Task 1 communications bandwidth loading analysis, a minimum support for gigabit or 10 gigabit backbone technologies have been identified as viable candidates for regional implementation. In the following technology tradeoff matrix, each potential technology is evaluated, based on 18 factors deemed critical towards the development of a successful network architecture. The following 18 factors provide the impetus for selection of candidate communications technology:

- Performance
- Cost of deployment
- Bandwidth options competitiveness
- Cost for a jurisdiction to interface to the technology
- Stability of the technology and associated standards
- Probability of downwards compatibility of new equipment
- Supportability of the technology based on its current life cycle status
- Probability of spare parts being available to support future maintenance activities
- Technology competition and probability of multiple vendors supporting common technology standards
- Interoperability verification of hardware/software from various vendors
- Ability of the technology and associated standards to support fault tolerance
- Scalability of the technology to support phased deployment of bandwidth
- Suitability of network architecture with consideration for fault tolerance
- Use of common equipment for core versus edge network
- Common network management across core and edge
- Support for IPv4 to IPv6 migration
- Support for IP multicast protocols
- Immunity from the effects of fiber dispersion

Each factor is based on a 0-10 scale, with 0 being least and 10 being the most desirable. Technologies represented with 0 value indicates total lack of support for the feature. The following rationale was used in determining each of the feature sets considered important to each of the technologies.

Performance of identified technology is based on the overall functional feature sets that are provided with standard equipment.

Equipment cost for initial deployment is derived from vendor responses to a standard minimum configuration of 2 ea. 10Gbps WAN, 4 ea. 1 Gbps MAN ports, CPU, switch fabric and associated software.

Bandwidth options are based on the ability to upgrade both WAN and MAN interfaces. Use of GBIC modules is considered to add to flexibility associated with initial equipment deployment, and as a cost effective method for device upgrade. Baseline configurations of equipment should include stand alone as well as EIA 19" card shelves that support growth thru module expansion or by cascaded switch configurations. Additional merit is given to interfaces which do not require associated bridge/routing to support interconnection.

Cost for a jurisdiction to interface with equipment is based on a redundant per port cost for connection from a jurisdiction to a switch residing on a regional network. For example, a good comparison would be to compare a 10/100/1000Base-Tx versus OC-12 in a 1+1 configuration.

Stability of the technology provides a view into current market trends based on proliferation of equipment, and general trends associated with the technology. Current trends in the MAG region indicate that jurisdictions are currently deploying Ethernet as a metropolitan area network solution supporting ITS.

Probability of backwards compatibility refers to the ability of the newest versions of the technology to remain compatible with prior releases. This primarily relates to hardware compatibility of the device.

Supportability of the technology refers to the ability of maintenance personnel to understand, operate, administer, maintain and provision the equipment. Furthermore, this relates to maintenance technician's ability to utilize current knowledge as used in the profession to support these activities. Ultimately, this can represent a reduction in the training curve associated with the deployment of the technology.

Probability of spare parts relates to the availability from Common Off The Shelf (COTS) suppliers to provide either complete equipment or module replacement. Of particular interest, is the understanding that multiple vendors may be utilized to obtain parts for deployed infrastructure. This also has a bearing on secondary cost associated with equipment maintenance.

Multiple vendor support for a technology is helpful from the standpoint of procurement, in that competitive specifications may be written. Additionally, this indicates that an open standard has been chosen, which reduces cost by allowing competition for materials.

Interoperability verification is a crucial component pertaining to the deployment of modern communications technology. It is a strong recommendation that some form of interoperability verification be provided between products manufactured by different vendors. Some universities and government agencies have on-going laboratory research programs that can save time and money regarding technology deployment. Two such programs are the University of New Hampshire's Interoperability Laboratory (IOL) and the National Institute of Standards and Technology (NIST). Interoperability verification is also provided by telecommunications equipment vendors, as part of an assurance program prior to equipment deployment in a customer's network (typically Regional Bell Operating Company (RBOC)). Reports pertaining to interoperability are available.

Support for fault tolerance is critical in evaluating potential network equipment. Linear, tree and star topologies rank the worst for recovery mechanisms. Point-to-point architectures are acceptable assuming fiber path diversity, otherwise, they will fail from a single fiber cut. Ring and mesh topologies support fiber path diversity, and will not isolate communications nodes on a single failure. Additionally, detection and switching away from a cut fiber should occur within 50 milliseconds. Protection algorithms that support this level of operation include: 1+1, UPSR, BLSR and EAPS. In addition to physical line (layer 2) switching, layer 3 protection should additionally be provided as is the case for IP communications. Rapid Spanning Tree Protocol (RSTP) is commonly used for re-route on IP packets.

Scalability of the technology relates to the ease in which bandwidth capacity can be added to an existing system. One of two methods typically provides this, the first being modular expansion and the second being the addition of a second equipment unit (chassis). GBIC modules are considered a favorable method for upgrade when the switch fabric can support the higher line rate.

Suitability of network architecture relates to the ability of the technology to adapt to existing fiber deployments in the region, and employ some method to protect the communications during normal operation of the equipment. The network architecture does not only apply to fiber utilization, but to such facets of organizational relationships and partitioning of user and service groups. Network architecture includes the communications pipes as well as integrated network management services that are provided by the platform selection.

Common equipment for network core and edge are important from a maintenance and network management perspective. This feature is rated by applying a unified maintenance approach based on technology selection.

Common network management should be provided across the infrastructure. Similarly, a common method of providing network management should be designed into the system. For example, network management from a SONET or DWDM system will utilize an out-of-band channel to relay information. This is different from gigabit Ethernet, which can be maintained in-band.

Support for IPv4 to IPv6 roadmap should be a concern if the decision is made to continue support for IP services for a regional ITS network. Currently, many Ethernet switches already provide dual implementation of IPv4 and IPv6. Devices which use protocol tunneling (SONET & WDM) are transparent to changes in layer 3 technology.

Support for IPv4 and IPv6 multicast is critical towards deployment of a modern networking technology. Devices which use tunneling (SONET, WDM) do not support multicast distribution of video. Instead, manual broadcast connections must be made to build and later tear down the connection. Technologies that operate using IP have the capability of performing these actions automatically.

Immunity from fiber dispersion effects is critical in moving forward with a regional communications architecture. Historically, the effects of PMD are especially significant for systems operating at 40 Gbps and above. However, under certain circumstances, systems operating at 10 Gbps have even had issues. It is important to note that systems implementing wavelength division multiplexing and SONET OC-768 are particularly vulnerable to PMD.

Table 5.0-1 provides the side by side comparison for each of the different technologies evaluated for deployment as a regional ITS communications backbone.

Table 5.0-1 Regional ITS Architecture Technology Feature Tradeoff Analysis

Technology	Performance	Equipment Cost of Deployment	Bandwidth Options	Cost for a jurisdiction to interface	Stability of the technology	Probability of backwards compatibility	Supportability of the technology	Probability of spare parts	Multiple vendor support	Interoperability verification of hardware/software	Support Fault Tolerance	Scalability of the Technology	Suitability of Network Architecture	Common Equipment for Core Versus Edge	Common Network Management	Supports IPv4 to IPv6 Migration	Supports IPv4 and IPv6 Multicast	Immunity to Fiber Dispersion Effects	Technology Total Points
Gig-E	7	9	5	10	10	10	10	10	10	10	9	9	9	10	10	10	10	10	**168**
10Gig-E	10	8	7	10	10	10	10	10	10	10	9	10	9	10	10	10	10	7	**170**
SONET	5	6	7	5	7	7	6	6	5	5	6	7	9	5	5	5	5	7	**108**
ATM	5	5	6	5	5	4	4	1	2	2	7	6	5	4	5	6	5	10	**87**
MPLS	10	4	7	9	6	7	6	6	5	5	9	8	9	5	8	9	10	7	**130**
RPR	5	6	7	6	5	6	5	5	4	4	8	7	10	5	5	5	5	7	**105**
WWDM	4	10	8	7	9	9	9	6	4	7	0	5	3	5	0	5	5	5	**101**
CWDM	6	7	9	7	9	8	7	5	4	6	6	7	6	5	5	5	5	4	**111**
DWDM	6	5	10	7	8	8	6	5	4	5	6	7	6	5	5	5	5	3	**106**
SONET Metro/Edge	6	7	7	6	7	7	6	5	5	5	6	6	6	6	5	8	7	5	**110**
GMPLS	7	3	7	8	4	7	4	3	3	2	6	6	9	5	8	9	10	7	**108**
PON	4	6	5	7	5	9	8	5	4	8	0	3	2	5	8	5	10	10	**104**

6.0 Technology Recommendation for a Regional ITS Communications Architecture

Overall, the three main competing technologies for telecommunications are still Ethernet, SONET and ATM. Of late, there has been a lot of activity related towards developing hybrid technologies to address particular market segment requirements. Specifically, the adoption of metropolitan Ethernet has evoked widespread implementation of front end brouter equipment within the SONET box. This has been done to compete with gigabit Ethernet in the metropolitan area network market. Based on available feature sets, commercial acceptance and cost, Ethernet is still dominating the competition.

The technology recommendation for a regional ITS network is 10 gigabit Ethernet. The 10Gig-E technology provides all of the modern features required for deployment. Multiple 10Gig-E rings can be developed across the MAG region using existing fiber. Should additional capacity beyond 10 Gbps be required, use of a second pair of fiber could be used to support a second or subsequent 10 Gbps rings. Alternatively, WWDM or CWDM devices could be utilized to support multiple channels using a single fiber pair. Again use of WDM technology requires either a) deployment of dispersion compensated fiber (SMF 28E) or b) use of optical repeaters where required. Should new fiber installations be based on dispersion compensated fiber, the next step in the evolution of Ethernet, which should operate at 100 Gbps could be deployed.

Ethernet technology provides backwards compatibility with previous versions of the standard. This is evidenced by understanding the most recent interface designation 10/100/1000 Base TX, which is capable of operating from 10 Mbps to 1,000 Mbps over unshielded twisted pair (UTP) cabling. Other features of Ethernet include Virtual LAN (VLAN) technology. VLANs can be secured and additionally filtered to allow only specific content to be sent across the connection. VLAN security is supported directly by use of IEEE 802.1x (RADIUS) authentication for the network.

Ethernet technology also includes the flexibility in its deployed architecture. Ethernet supports ring, mesh and point-to-point communications topologies over copper, fiber or wireless. Pairing off from the architecture is the ability of 10Gig-E to provide protection switching within 50 msec by using the EAPS protocol. Additionally, Ethernet benefits from the use of path diversity in the network design, and can make use of RSTP to take advantage of such connections.

Add-drop requirements for a regional 10Gig-E network are very simple. The 10Gig-E backbone switch can support 1 Gbps Ethernet over single mode fiber. If the communications requirements for a jurisdiction are substantially less, a fast Ethernet port operating at 100 Mbps could be used instead. A common interface from a jurisdiction to a regional architecture should be based on a Gig-E fiber or electrical interface.

Ethernet technology provides Quality of Service (QoS) mechanisms necessary to ensure the delivery of time sensitive data such as IP voice and video. In addition, IP video can be multicast using both PIM sparse and dense modes. Ethernet is extremely efficient handling IP video communications.

Ethernet technology has been used for ITS center communications since the early 1990s. In fact, Ethernets were originally connected to each other using SONET technology. Today, Ethernet connects Ethernet across the MAN/WAN cloud. This benefits OAM&P and substantially lowers the total cost of ownership. Given the proliferation of Ethernet technology in terms of the number of ports sold, there exists a high probability that Ethernet will continue to have support for a number of years ahead.

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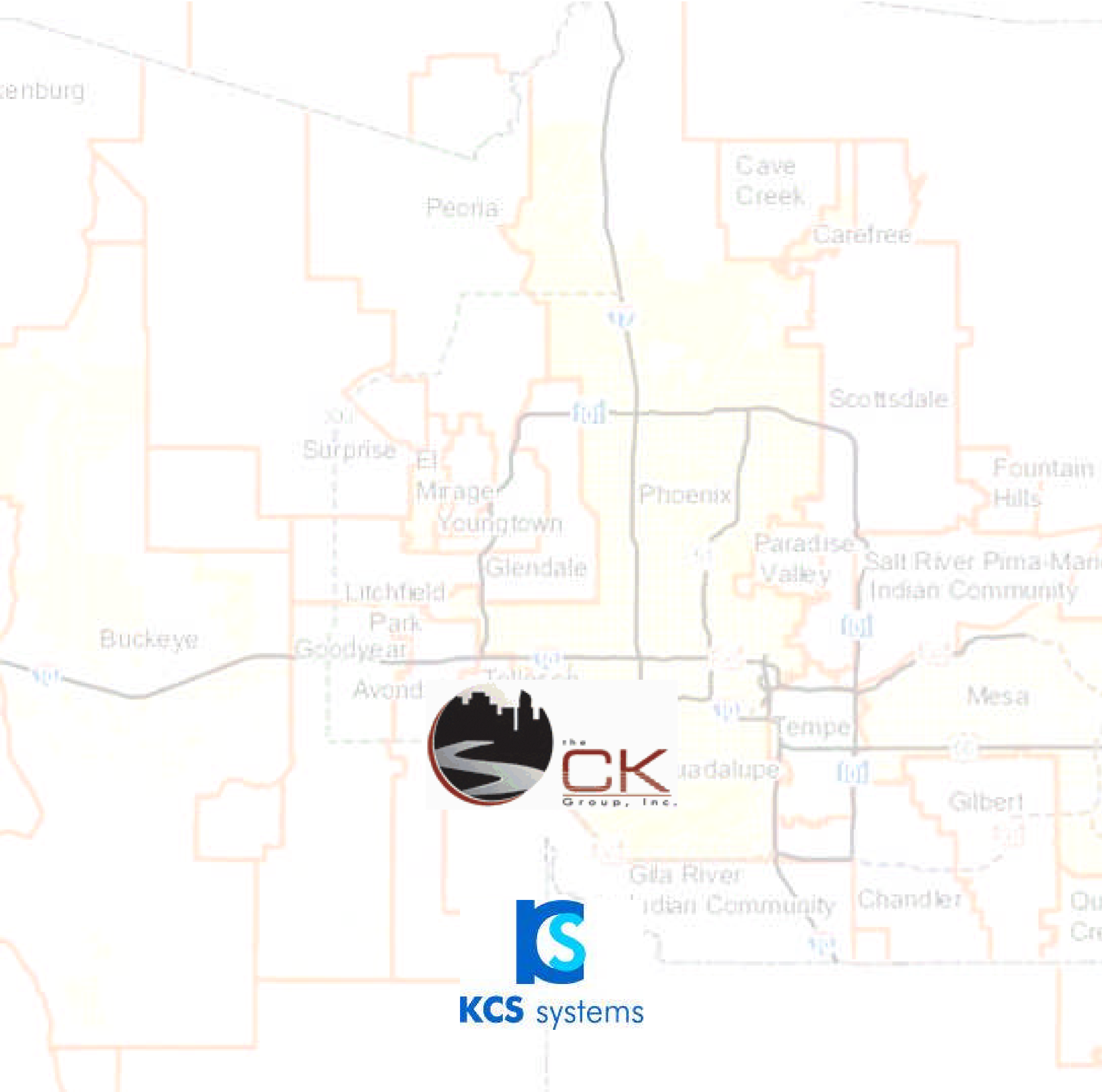

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